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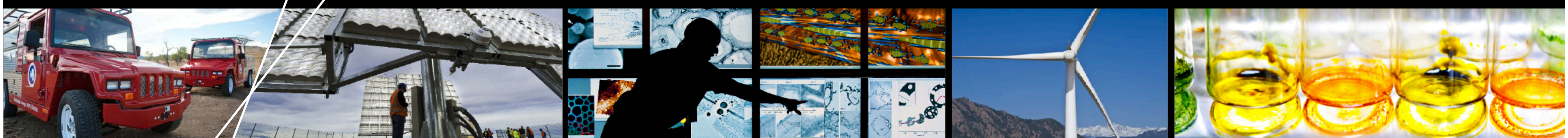
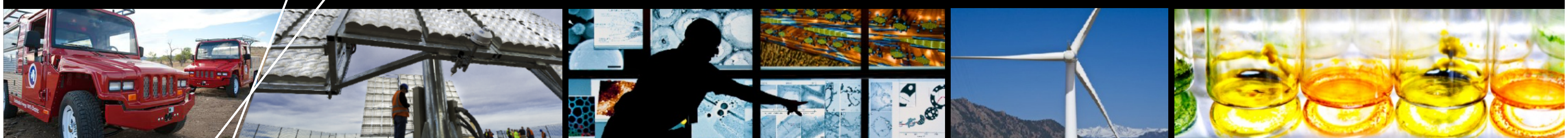
WWSIS2: Production simulation results



Technical Review Committee results meeting

Greg Brinkman

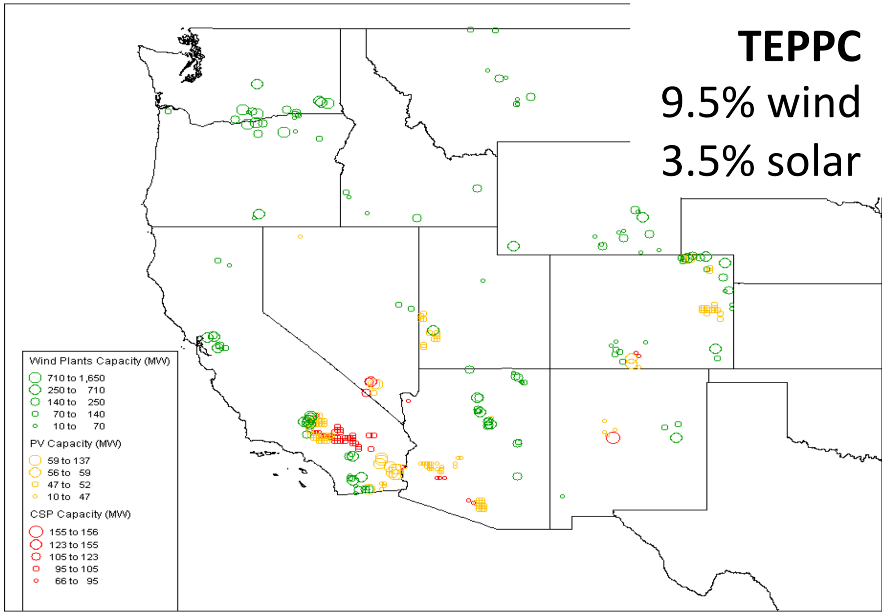
11/28/2012



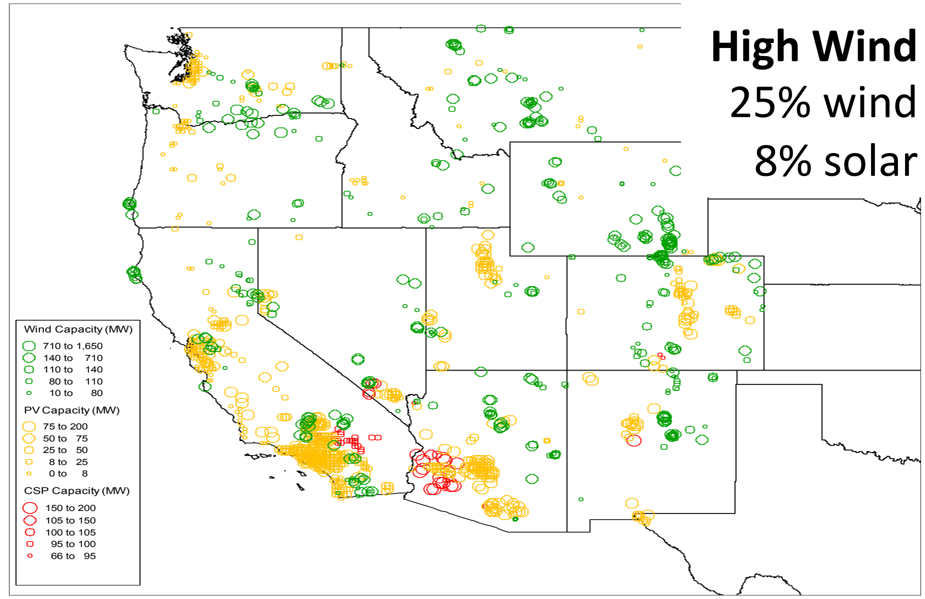
Scenarios

Siting with REEDS model

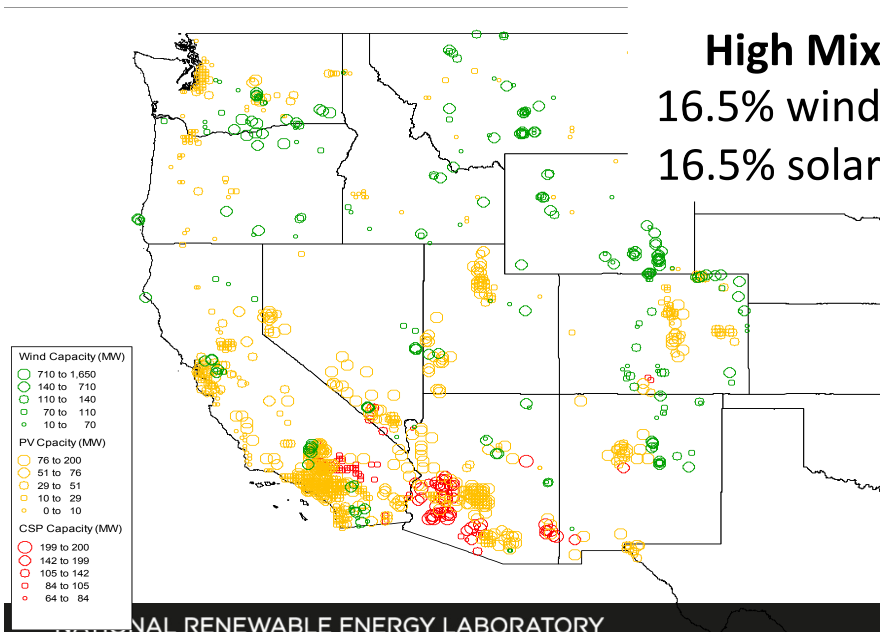
TEPPC
9.5% wind
3.5% solar



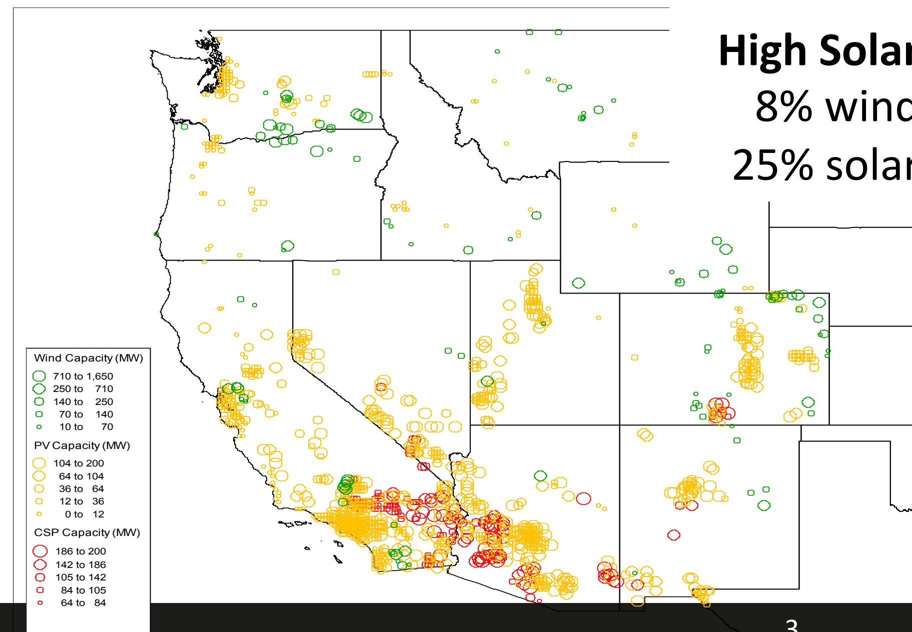
High Wind
25% wind
8% solar



High Mix
16.5% wind
16.5% solar



High Solar
8% wind
25% solar



Scenarios

	PV (MW)	CSP (MW)	Wind (MW)	Total (MW)
TEPPC (9.5% wind, 3.5% solar)	7037	4352	27,903	39,328
High Wind (25% wind, 8% solar)	20,063	6536	63,843	90,442
High Mix (16.5% wind, 16.5% solar)	40,374	13,997	43,120	97,491
High Solar (8% wind, 25% solar)	61,940	21,527	23,359	106,826

- All wind and solar is sited in US portion of Western Interconnection. 2020 peak WECC load is 171 GW, of which 147 GW is in the US. TEPPC case uses same MW as TEPPC but all sited in US, giving 13% total VG penetration
- CSP has 6 hours storage
- WECC TEPPC 2020 PC1 case

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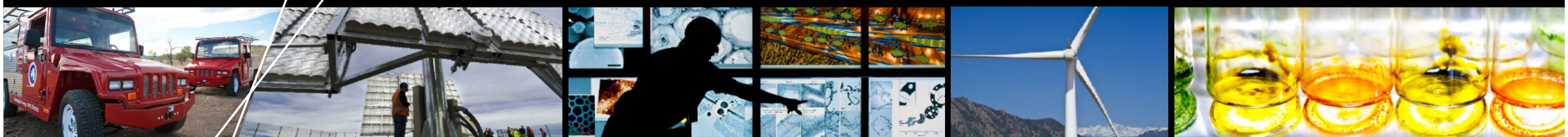


Inputs already reviewed by TRC

Input data

- **Previously discussed today**
  - Wind (actual 5-min, hourly 4HA and DA forecast)
  - Solar (actual 5-min, hourly 4HA and DA forecast)
  - Reserves
  - Wear-and-tear costs of cycling
  - Emissions (part-load, startup, and ramping)

Major assumptions (transmission)

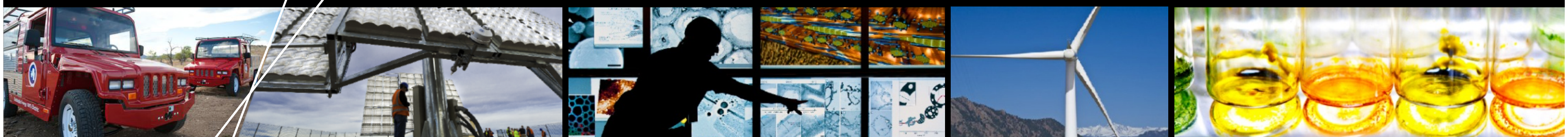
- **Zonal analysis (20 WECC LRS zones)**
- **Reserve sharing by LRS zone for contingency and flex, by all of WECC for reg (RBC)**
- **Least-cost dispatch optimized over all of WECC**
- **No hurdle rates**
    - Could be future sensitivity

Major assumptions

- **No carbon tax/cost**
- **All profiles based on 2006 meteorology year**
- **Hydro schedules determined in DA market**
  - Monthly energy limit, monthly min/max power for every dispatchable unit based on TEPPC work and EIM limits
  - Monthly limits disaggregated to daily limits based on simple monthly optimization
  - DA optimization disaggregates daily limits to hourly
  - Hourly schedules fixed for 4HA and RT

Production simulation analysis

- **PLEXOS – security constrained unit commitment and economic dispatch**
- **Day-ahead unit commitment**
  - Commit long start generators (coal, nuclear)
  - Hourly resolution
- **4-hour-ahead unit commitment**
  - Commit medium start generators (gas CC, gas steam)
  - Hourly resolution
- **Real Time dispatch**
  - Commit fast start generators (gas CT, IC)
  - 5 minute resolution

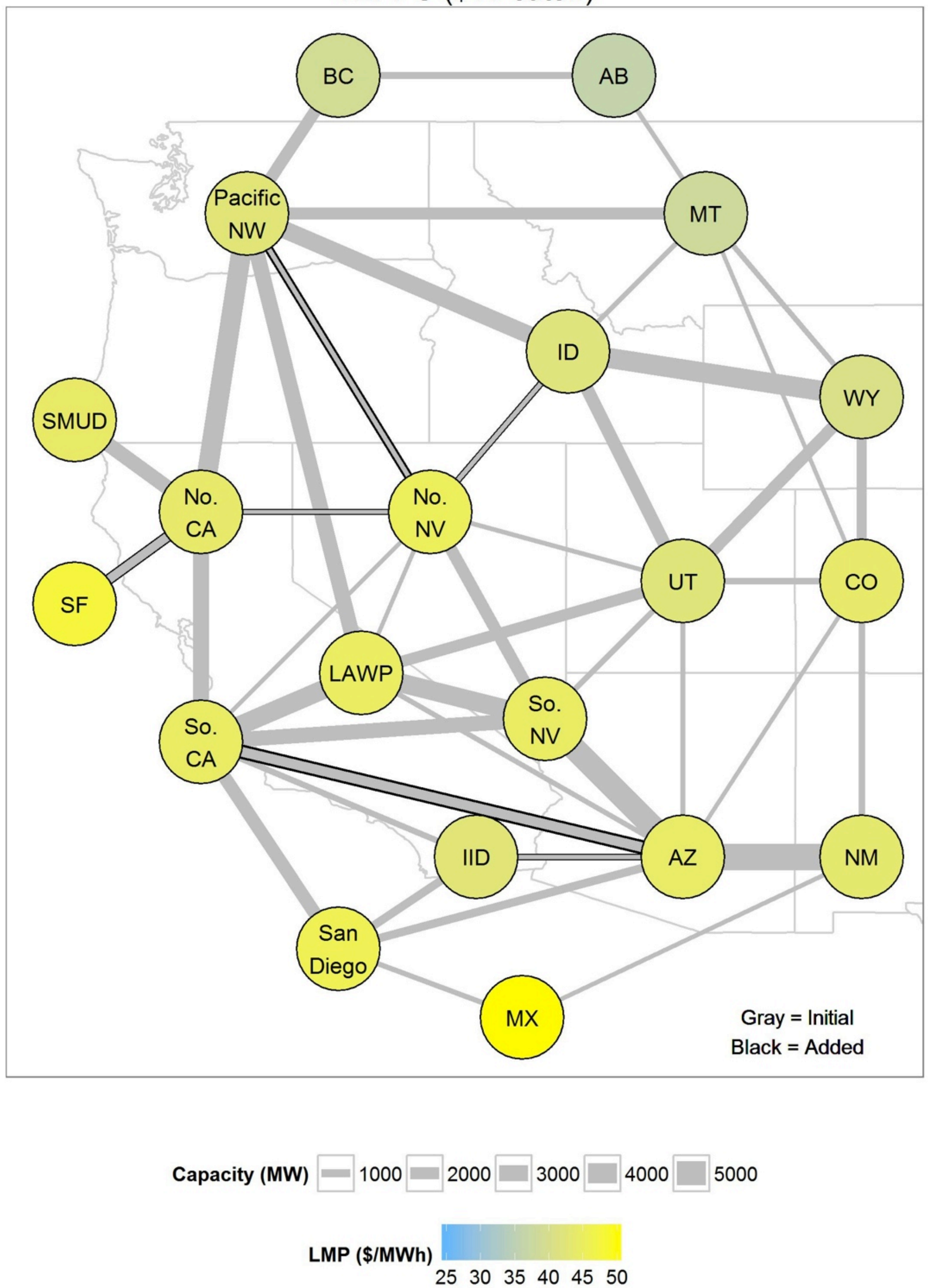


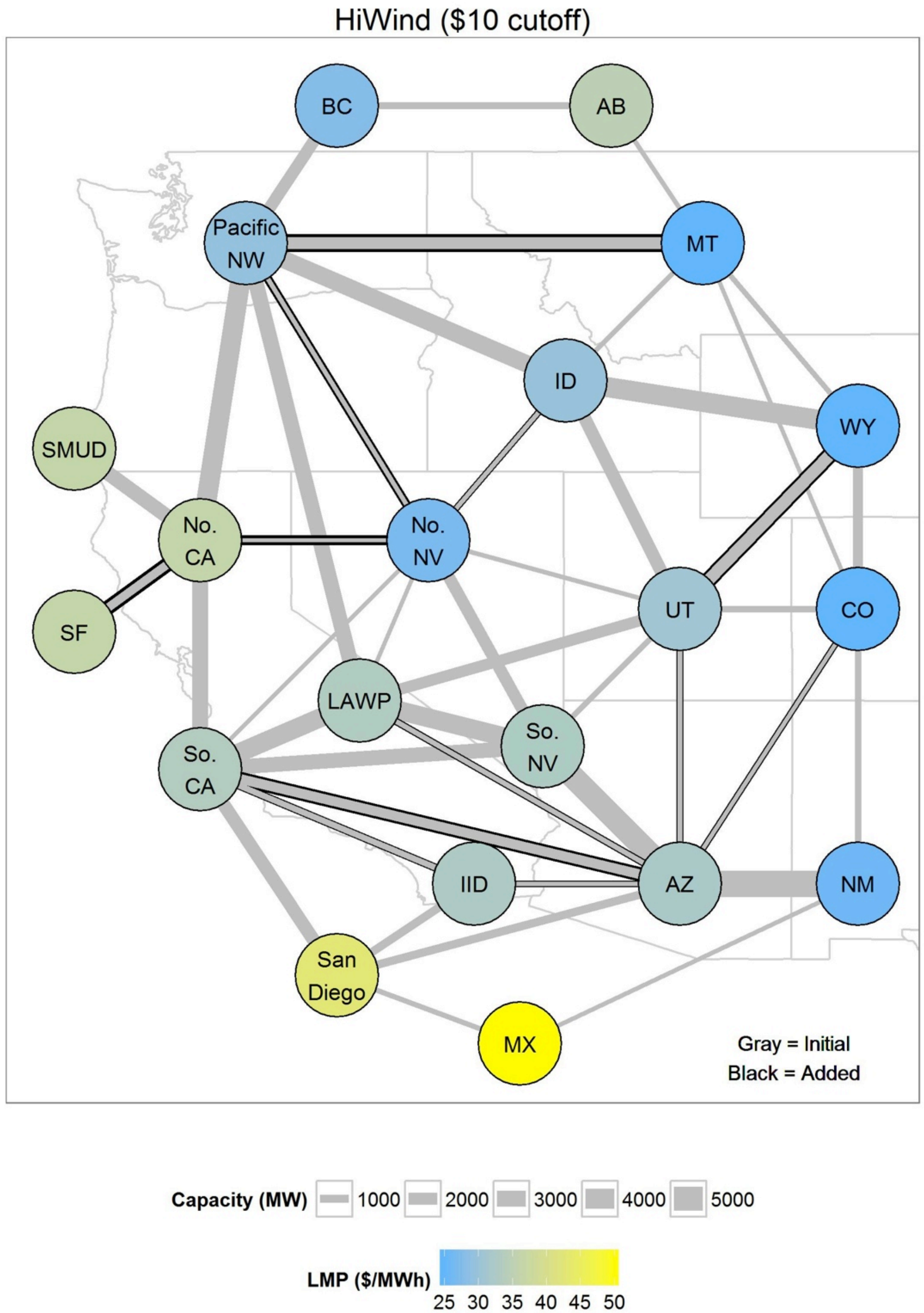
Transmission expansion

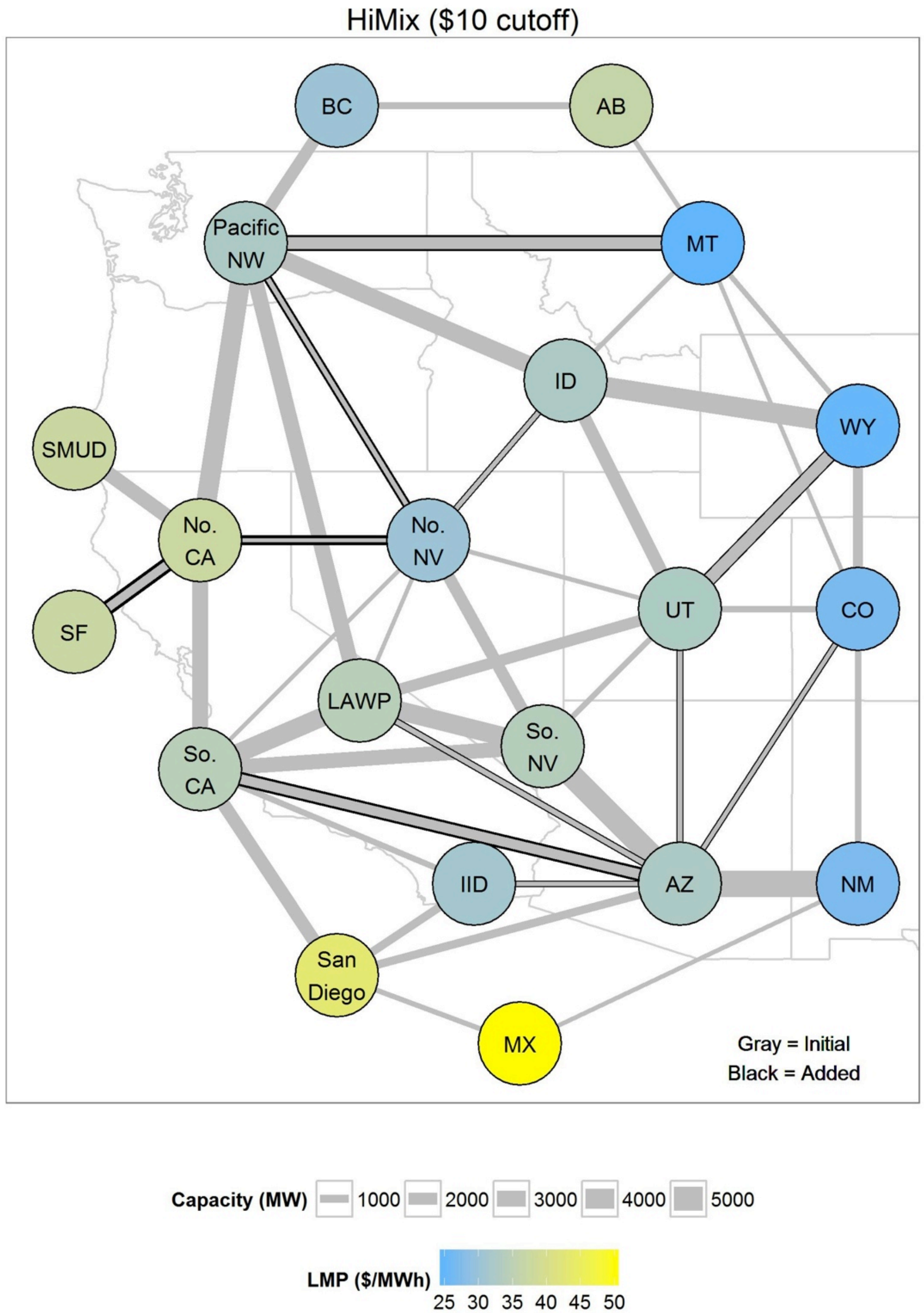
Transmission Expansion

- Expanded capacity on existing interfaces
- Ran PLEXOS for full year iteratively
- Increased capacity by 500 MW until shadow price across interface was reduced below fixed cutoff
- Examined production cost and curtailment metrics
- Tested cutoffs and selected cutoff value of $10/MWh

TEPPC ($10 cutoff)




HiWind ($10 cutoff)
BC
AB
Pacific NW
MT
ID
WY
SMUD
No. CA
No. NV
SF
UT
CO
LAWP
So. NV
So. CA
IID
AZ
NM
San Diego
MX
Gray = Initial
Black = Added
Capacity (MW) 1000 2000 3000 4000 5000
LMP ($/MWh) 25 30 35 40 45 50



HiMix ($10 cutoff)
BC
AB
Pacific NW
MT
ID
WY
SMUD
No. CA
No. NV
SF
UT
CO
LAWP
So. NV
So. CA
IID
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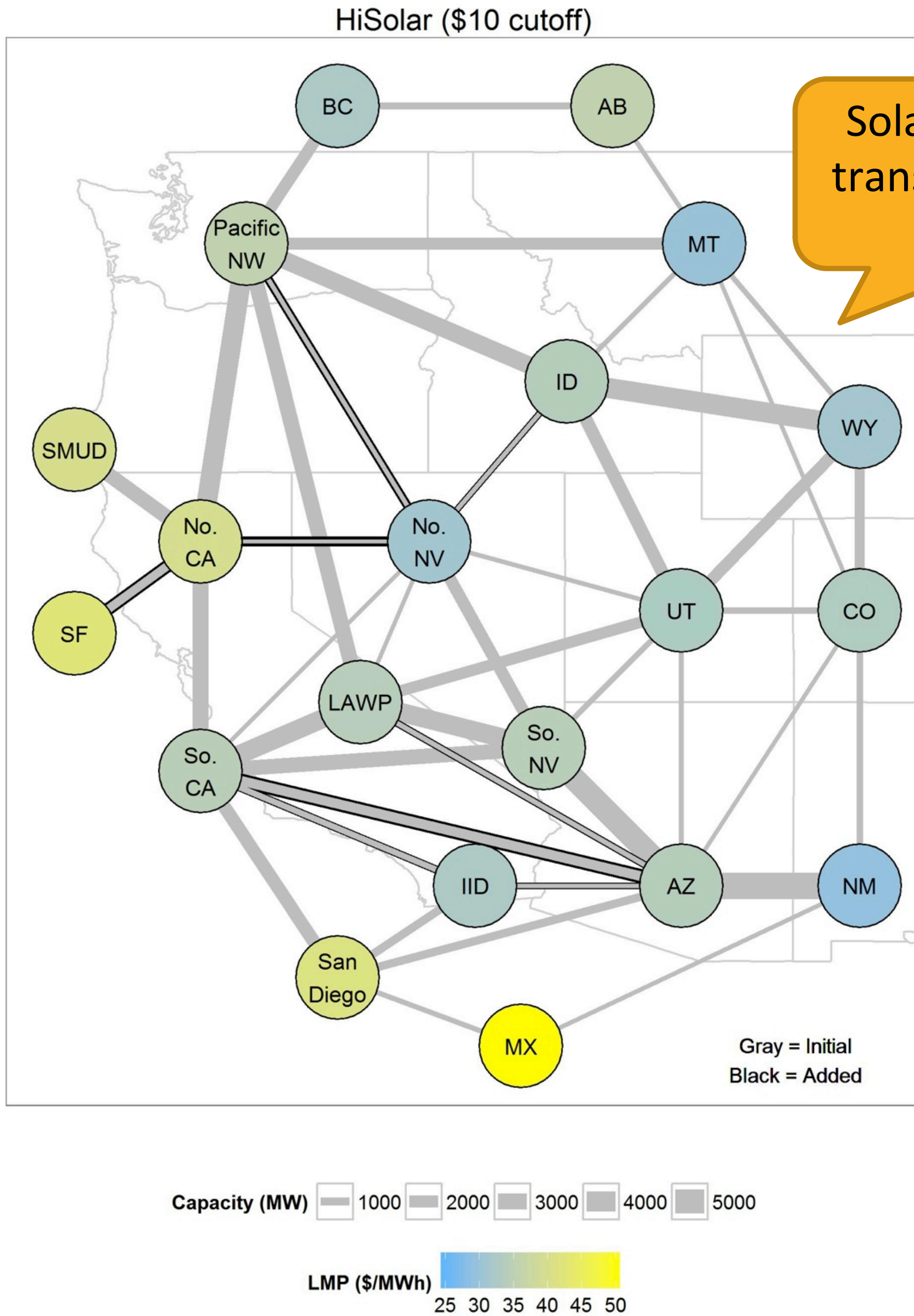
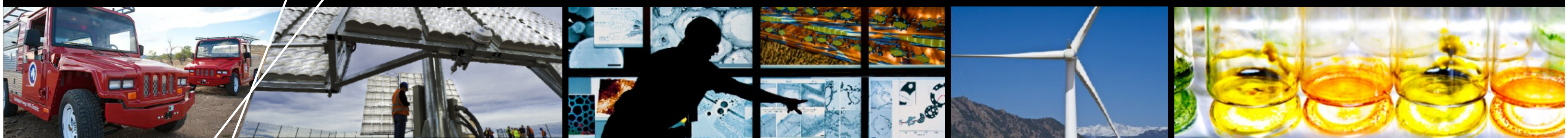
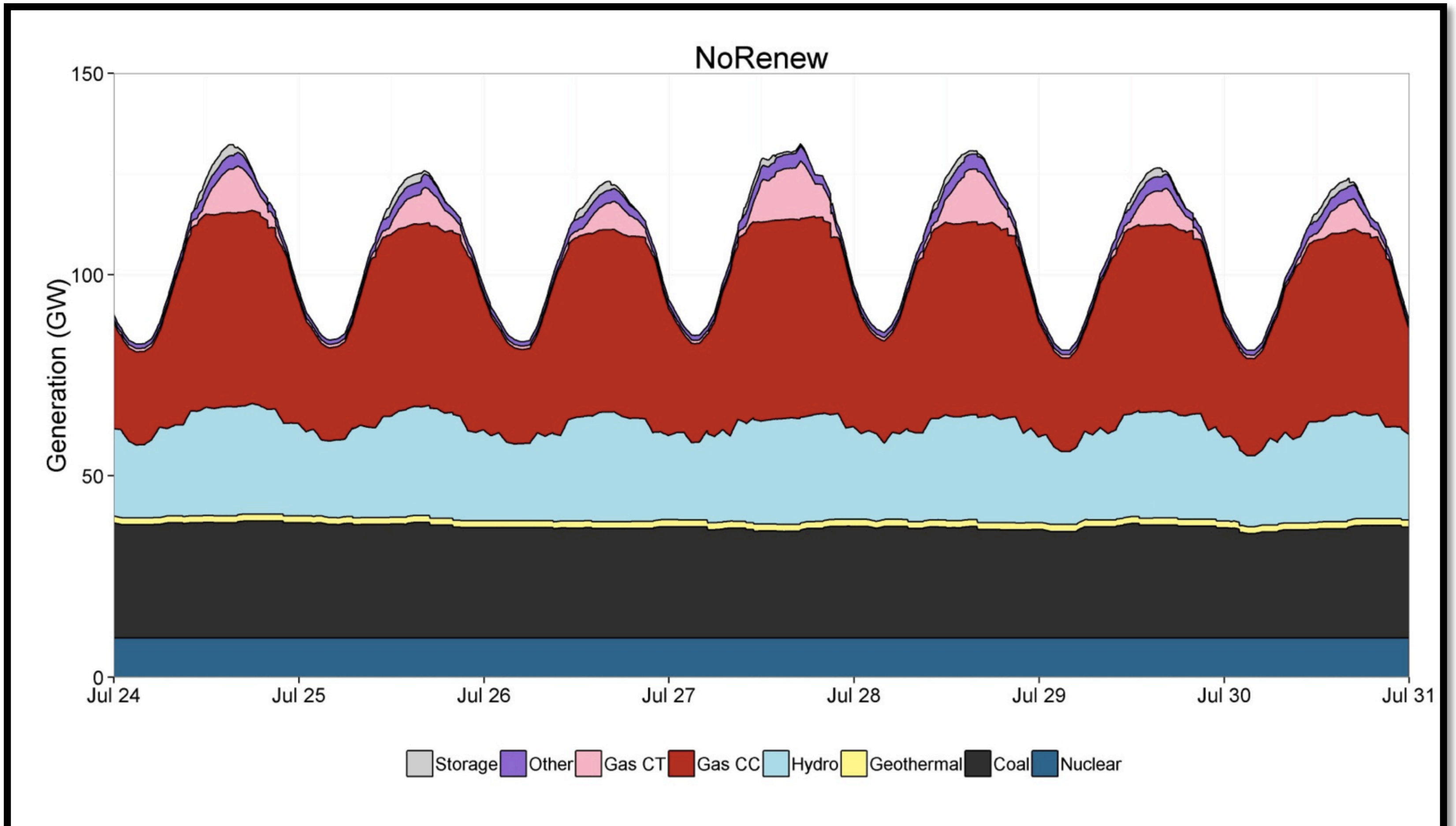


Solar leads to less transmission builds than wind



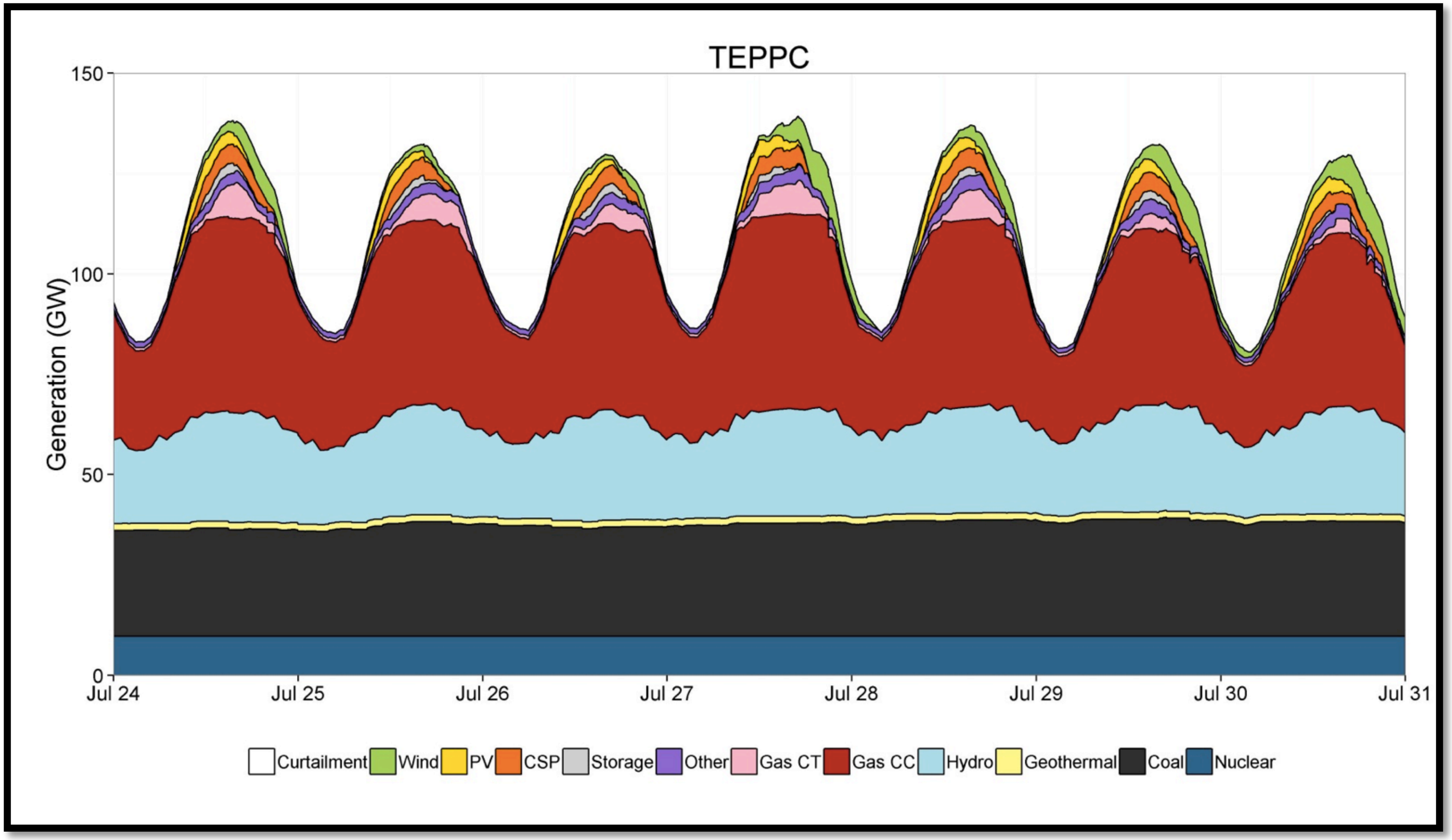
Results - dispatch

Summer Dispatch



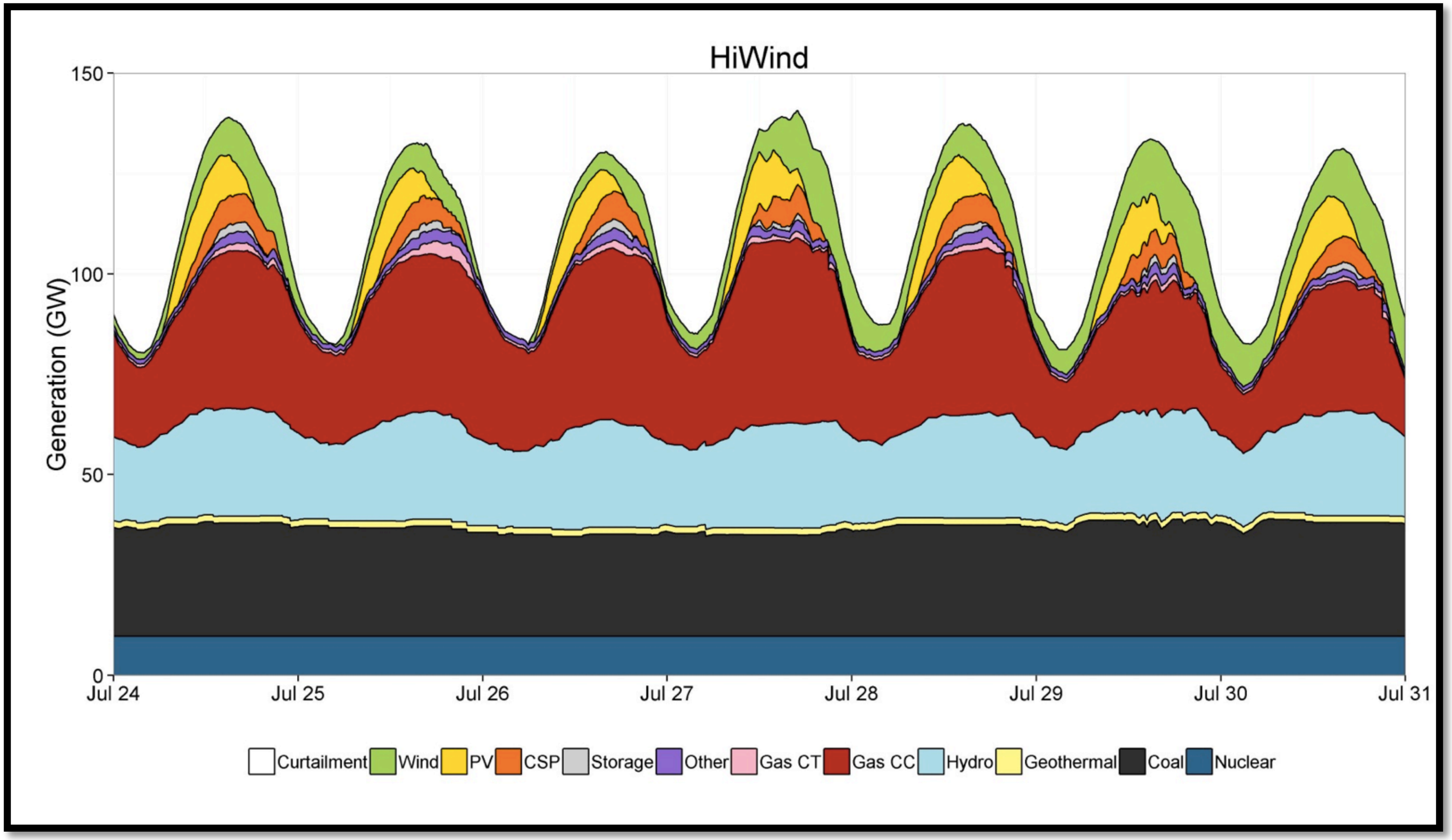
76-DispatchCurtSummer_NoRenew

Summary Dispatch



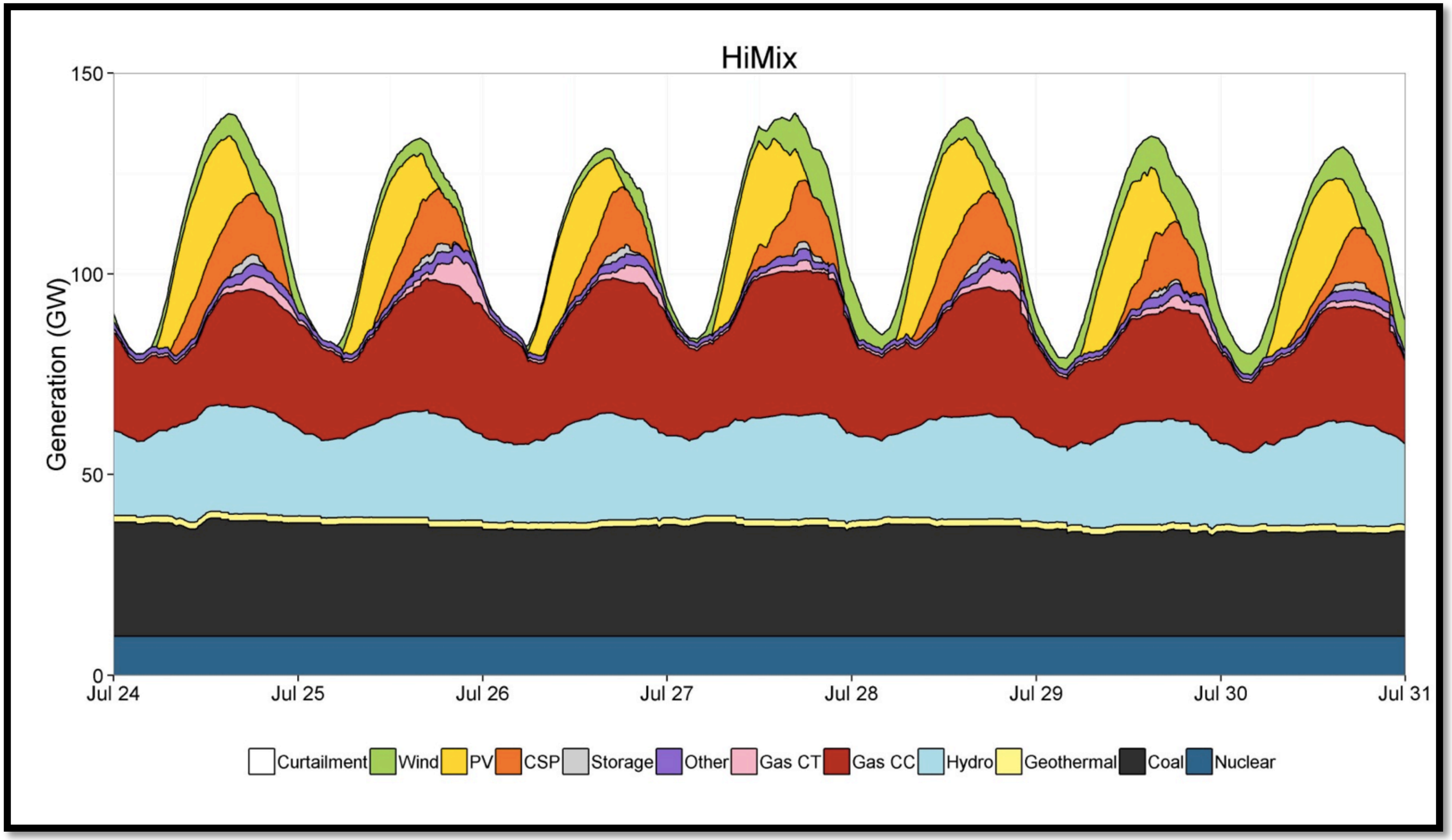
72-DispatchCurtSummer_TEPPC

Summer Dispatch



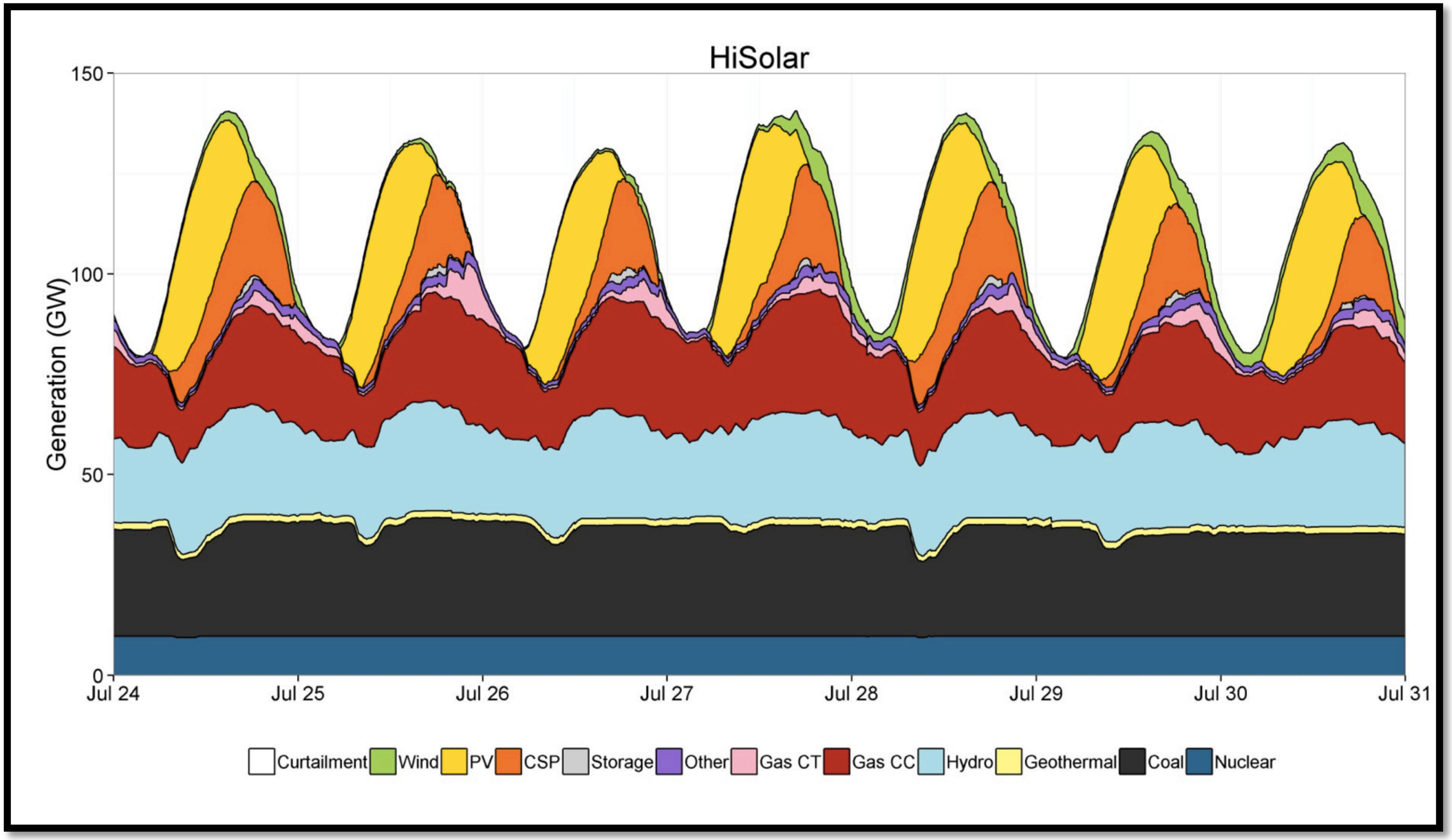
73-DispatchCurtSummer_HiWind

Summer Dispatch



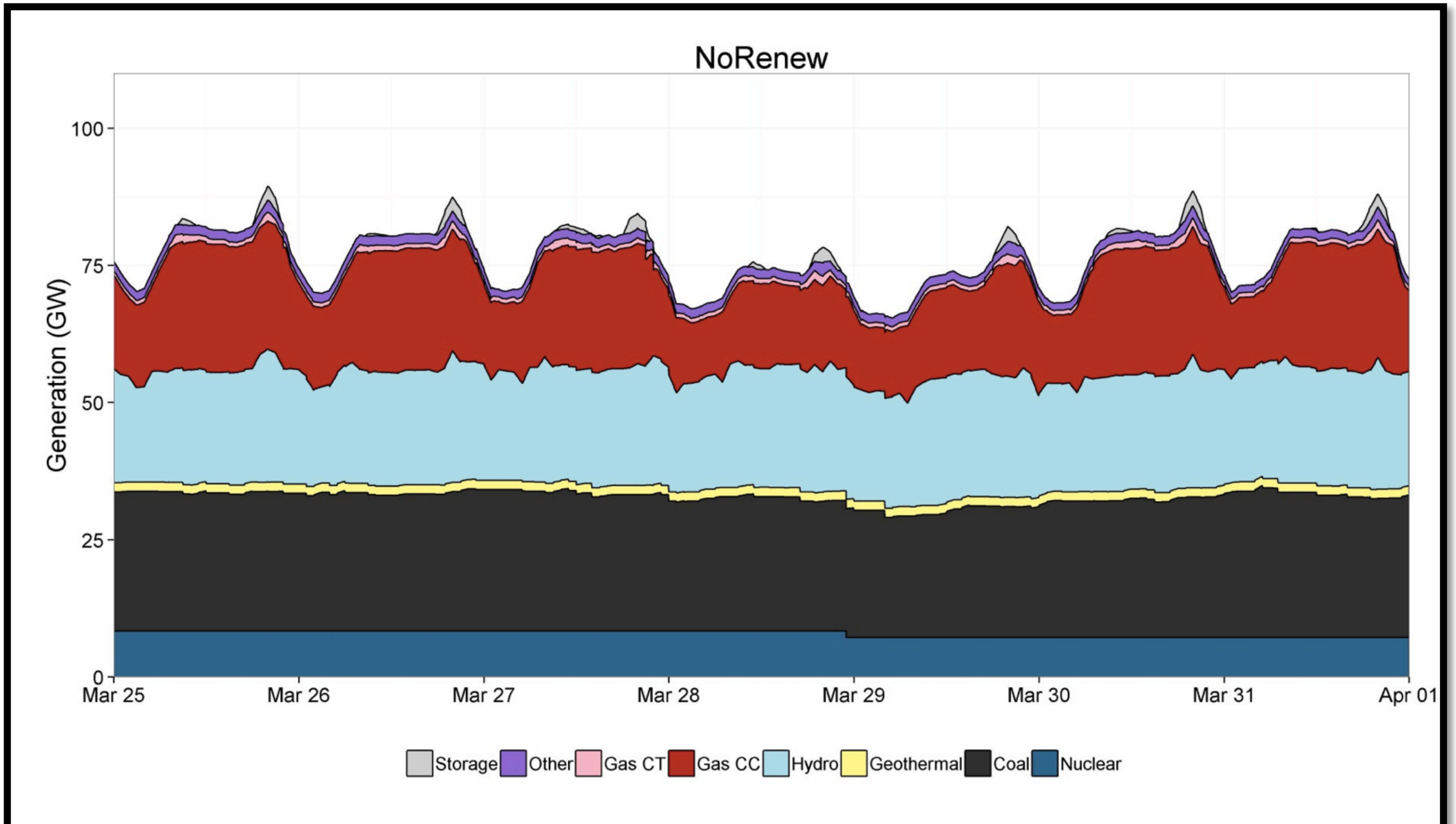
74-DispatchCurtSummer_HiMix

Summer Dispatch



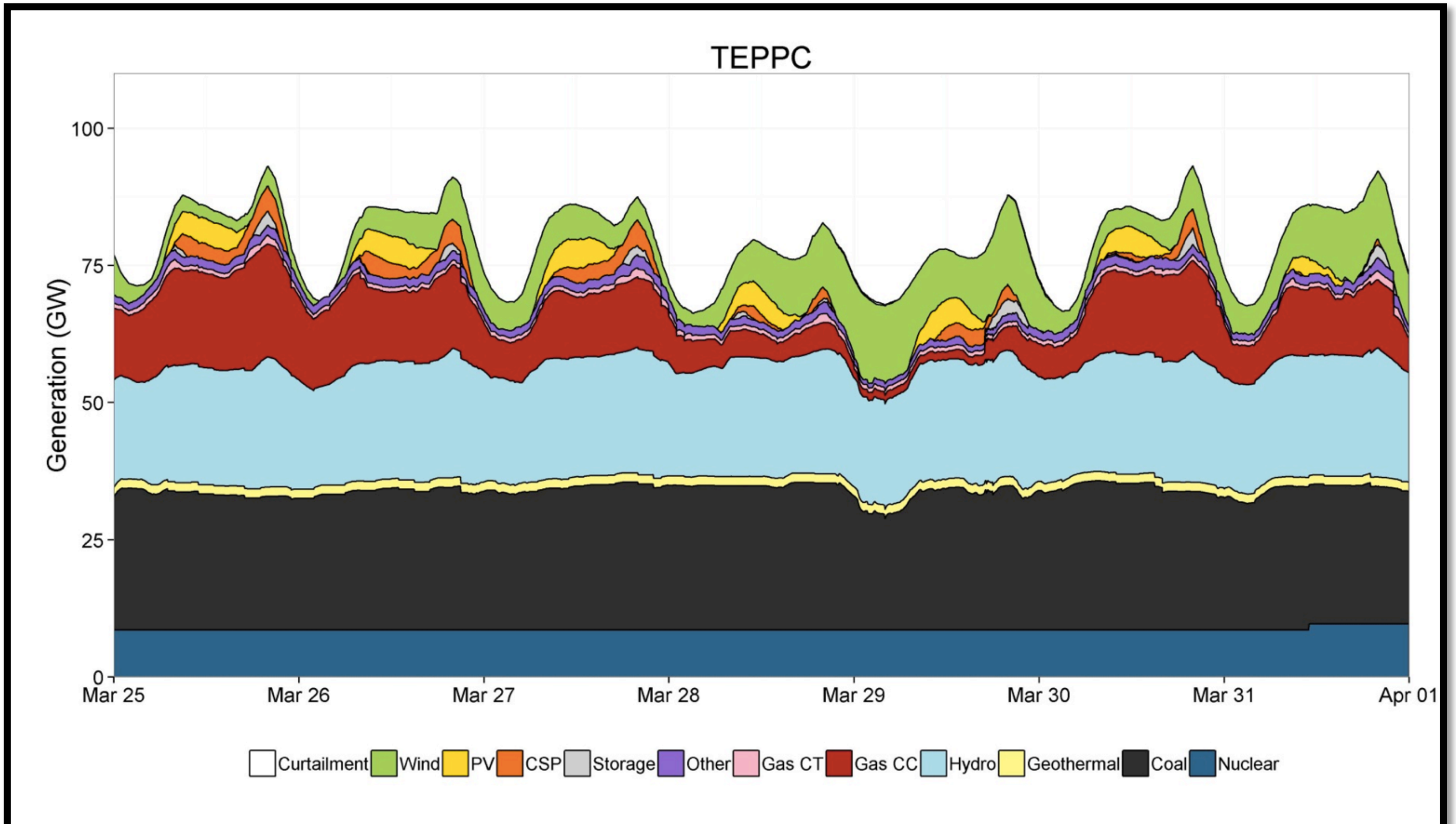
75-DispatchCurtSummer_HiSolar

Spring Dispatch



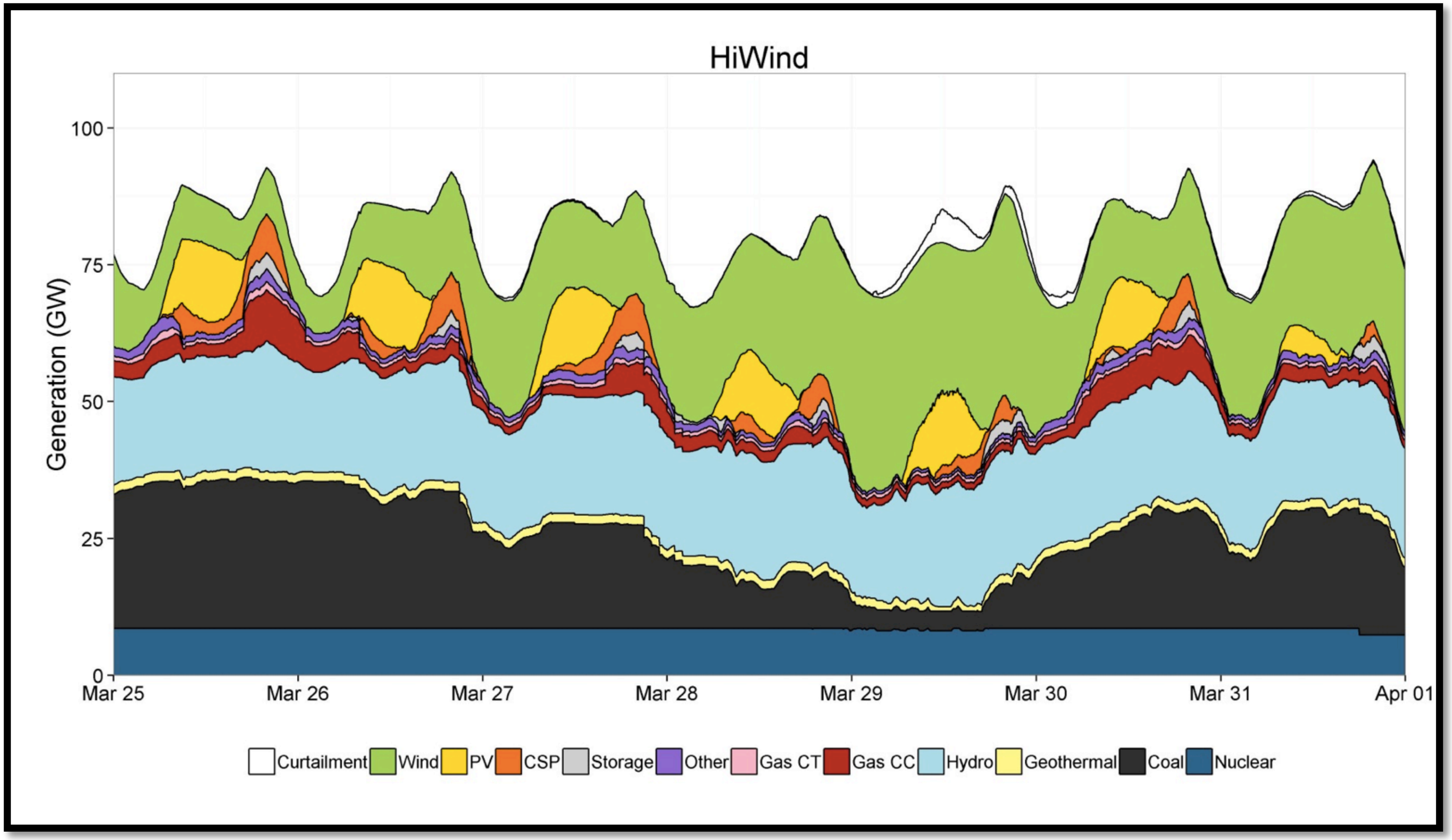
71-DispatchCurtSpring_NoRenew

Spring Dispatch



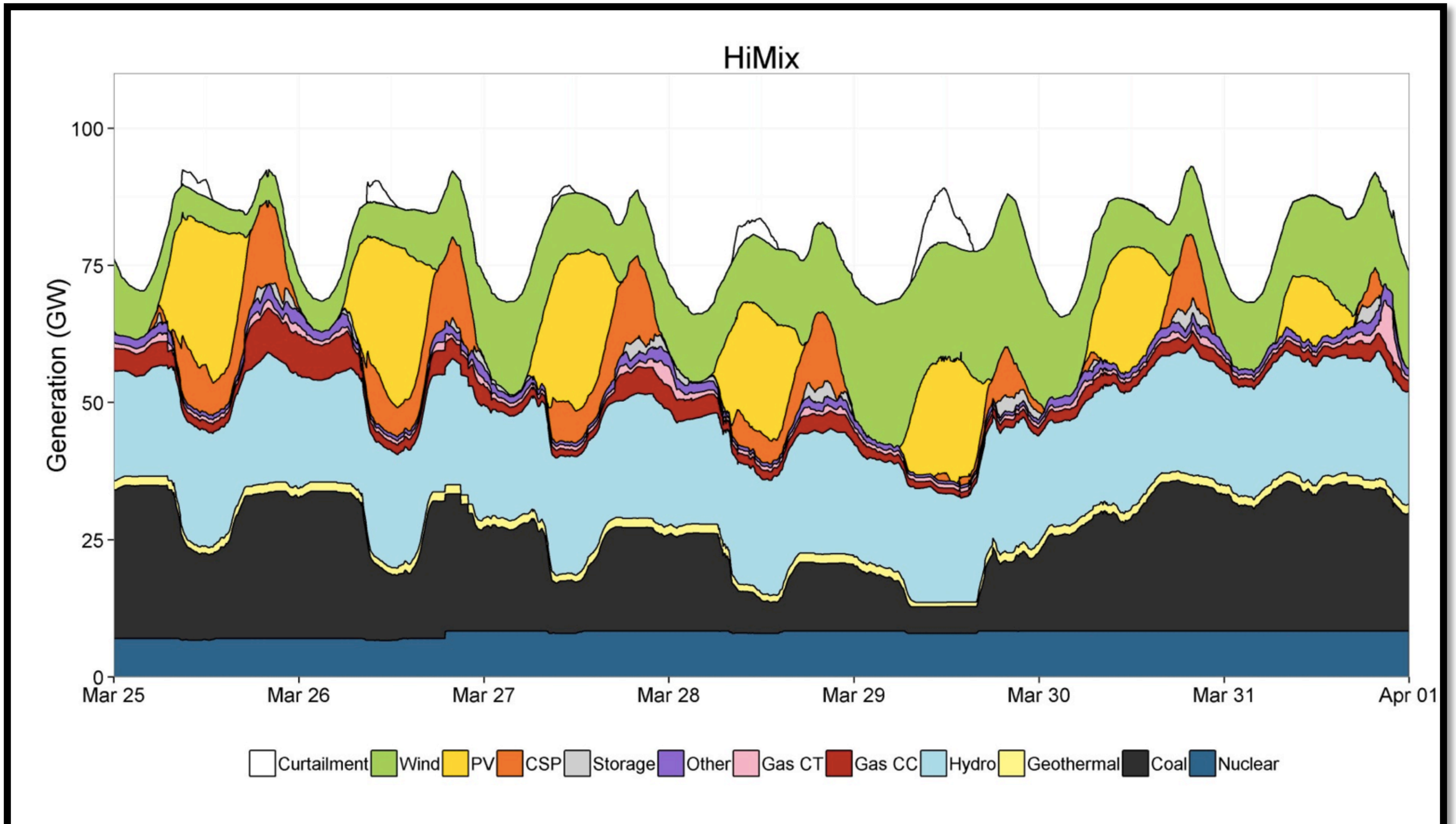
77-DispatchCurtSpring_TEPPC

Spring Dispatch



78-DispatchCurtSpring_HiWind

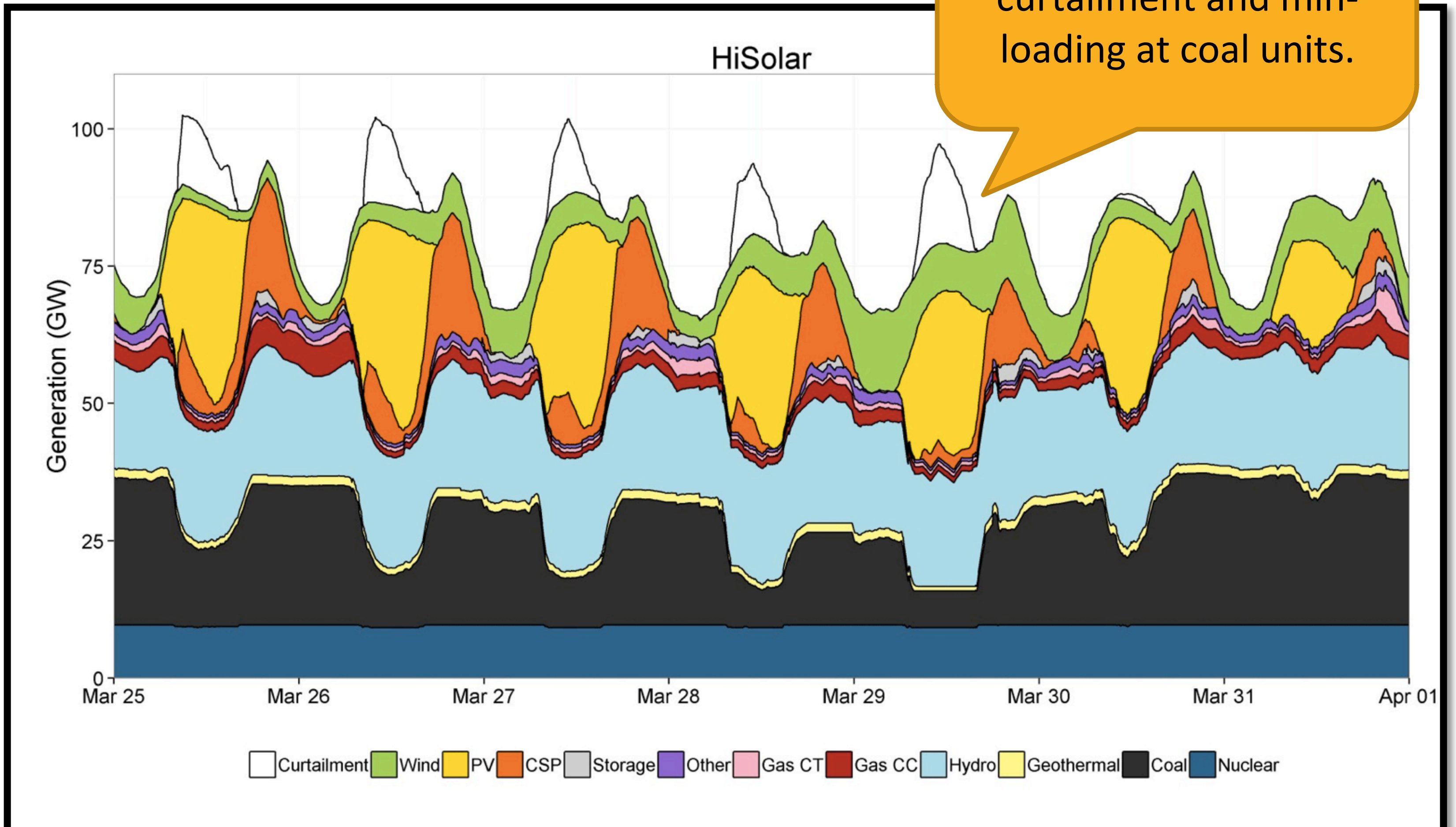
Spring Dispatch



79-DispatchCurtSpring_HiMix

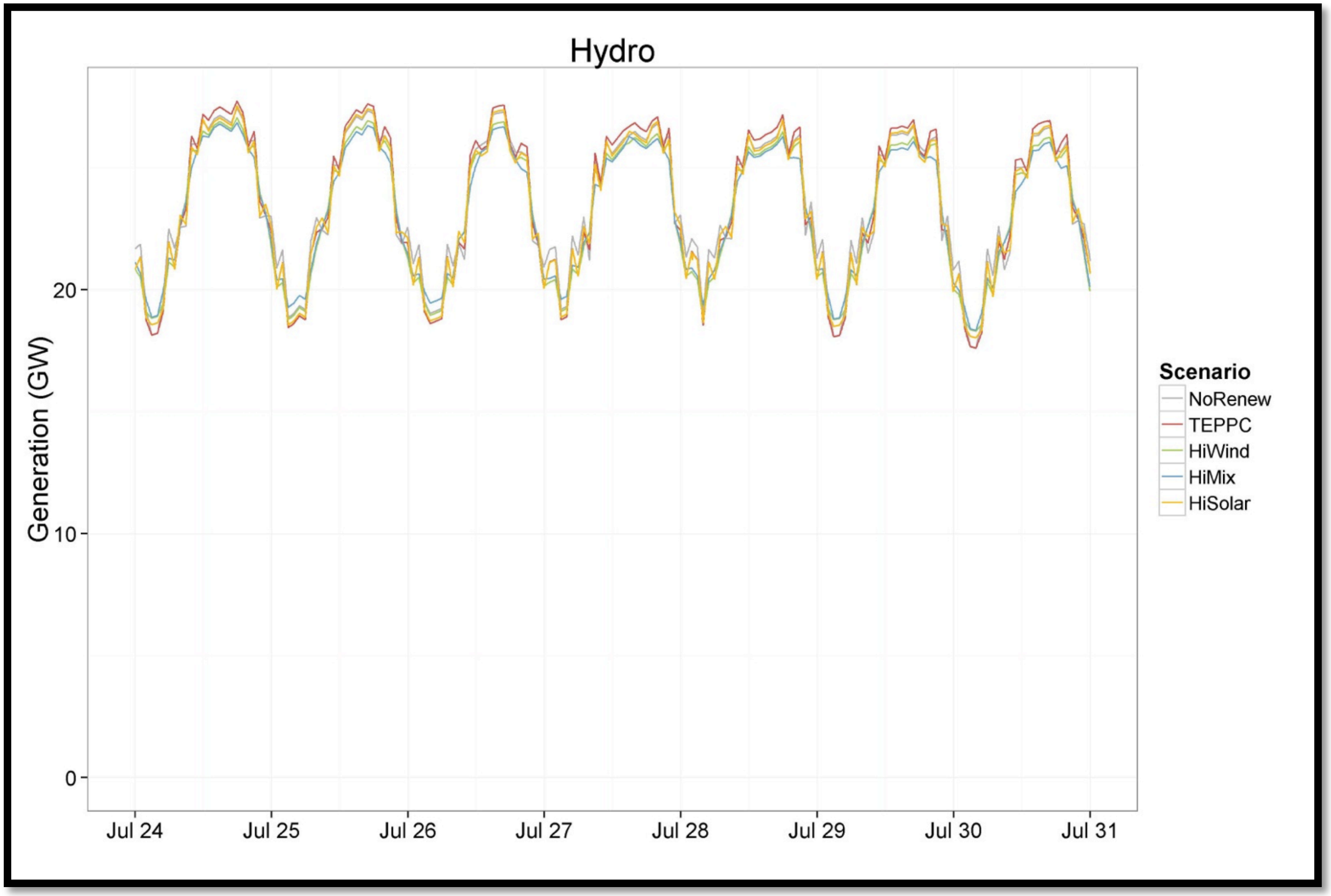
Spring Dispatch

Solar leads to mid-day curtailment and min-loading at coal units.



80-DispatchCurtSpring_HiSolar

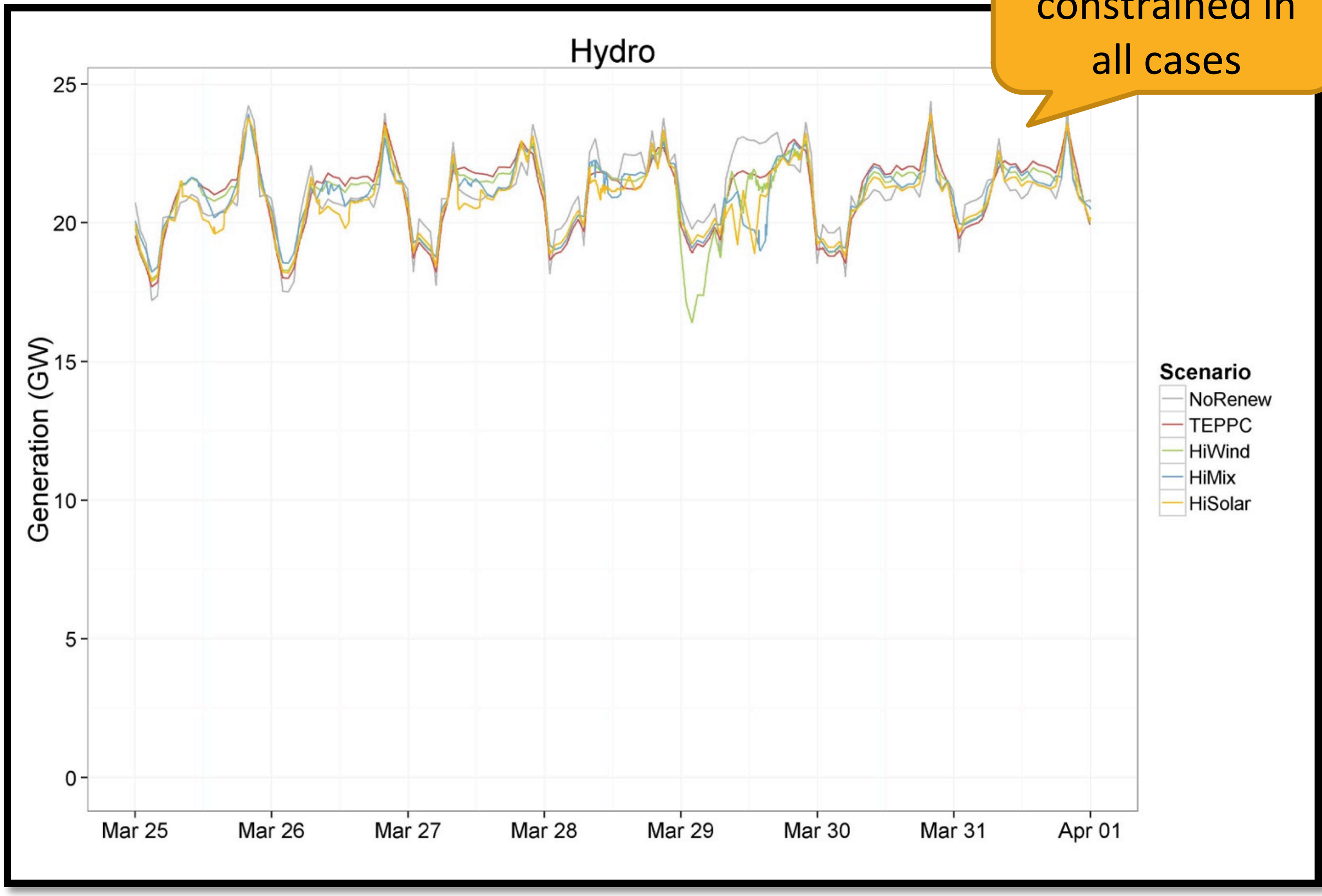
Hydro - Summer Dispatch



81-TimeGen_SummerHydro

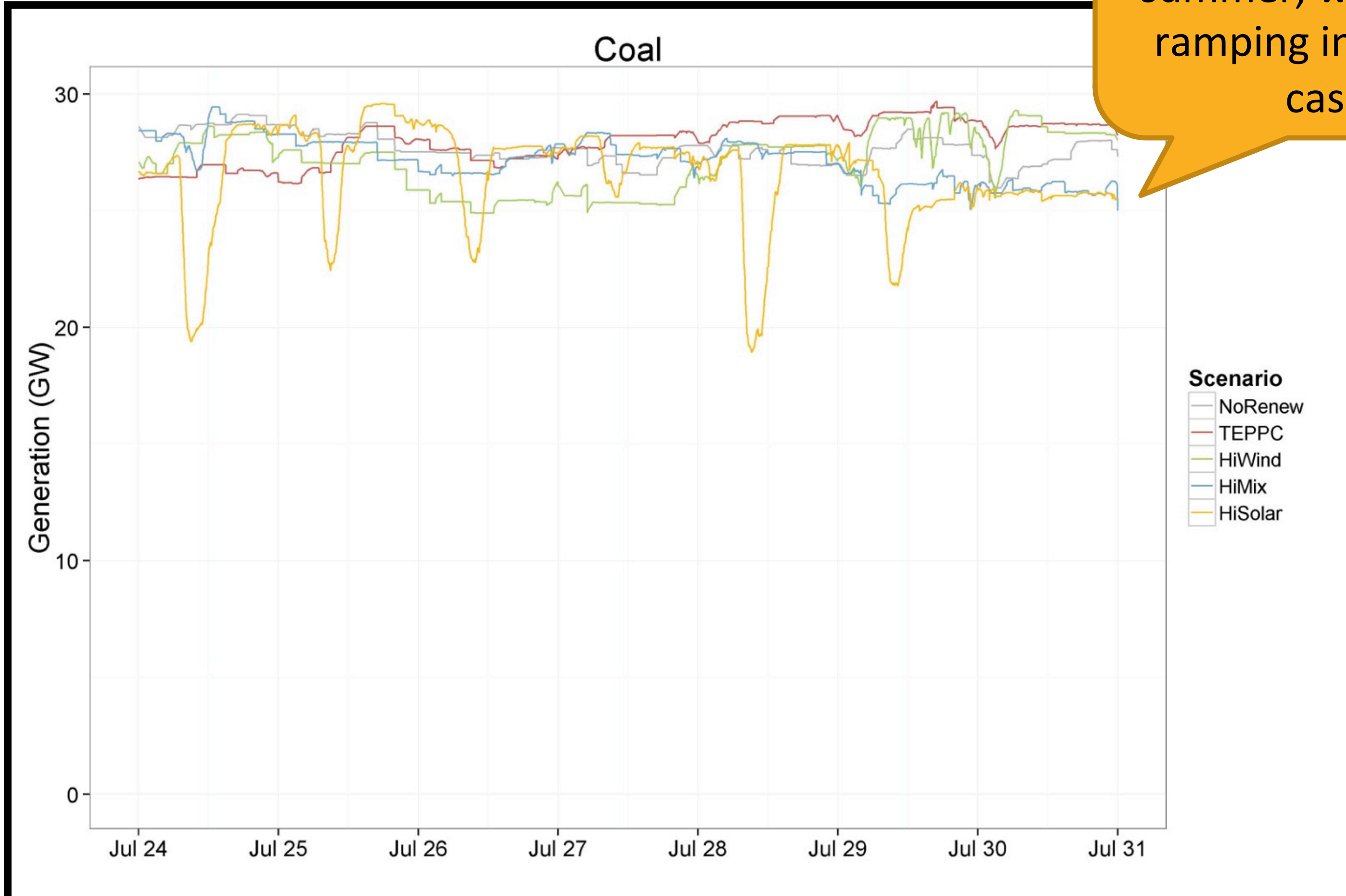
Hydro - Spring Dispatch

Hydro is highly constrained in all cases



82-TimeGen_SpringHydro

Coal - Summer Dispatch

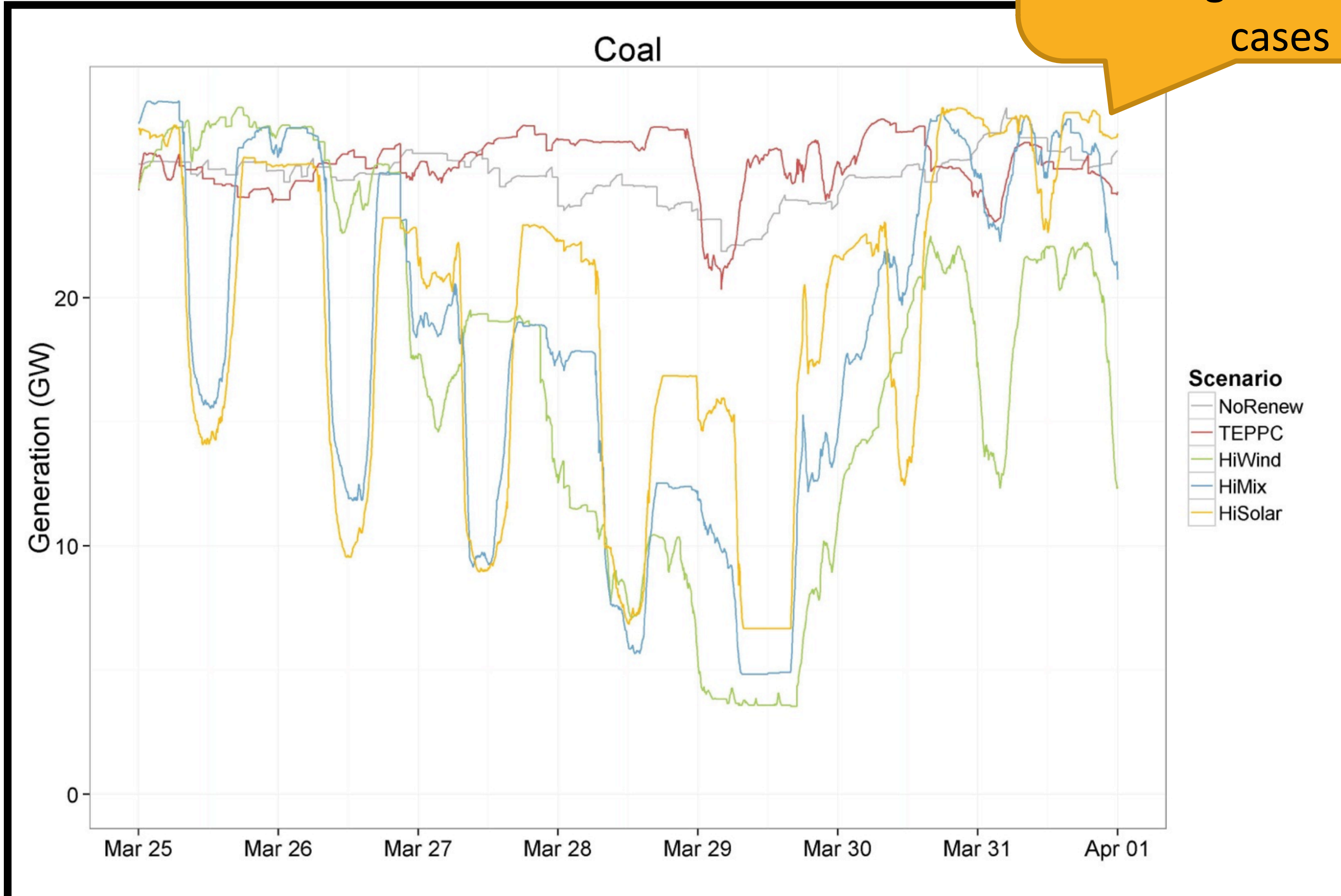


Coal is primarily baseload during summer, with some ramping in HiSolar case

83-TimeGen_SummerCoal

Coal - Spring Dispatch

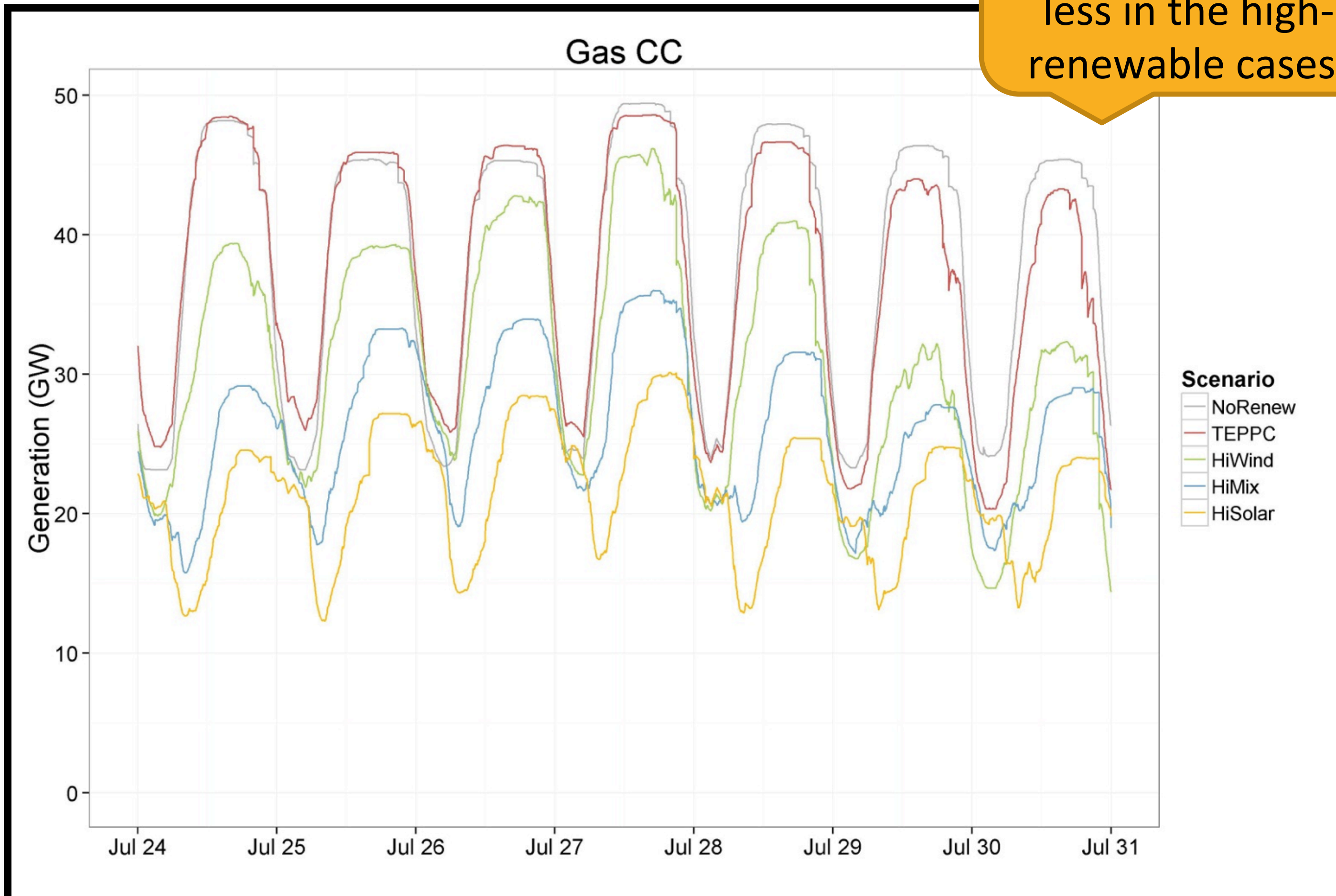
In spring, coal cycles on a ~weekly time scale and follows load daily in the high-renewable cases



84-TimeGen_SpringCoal

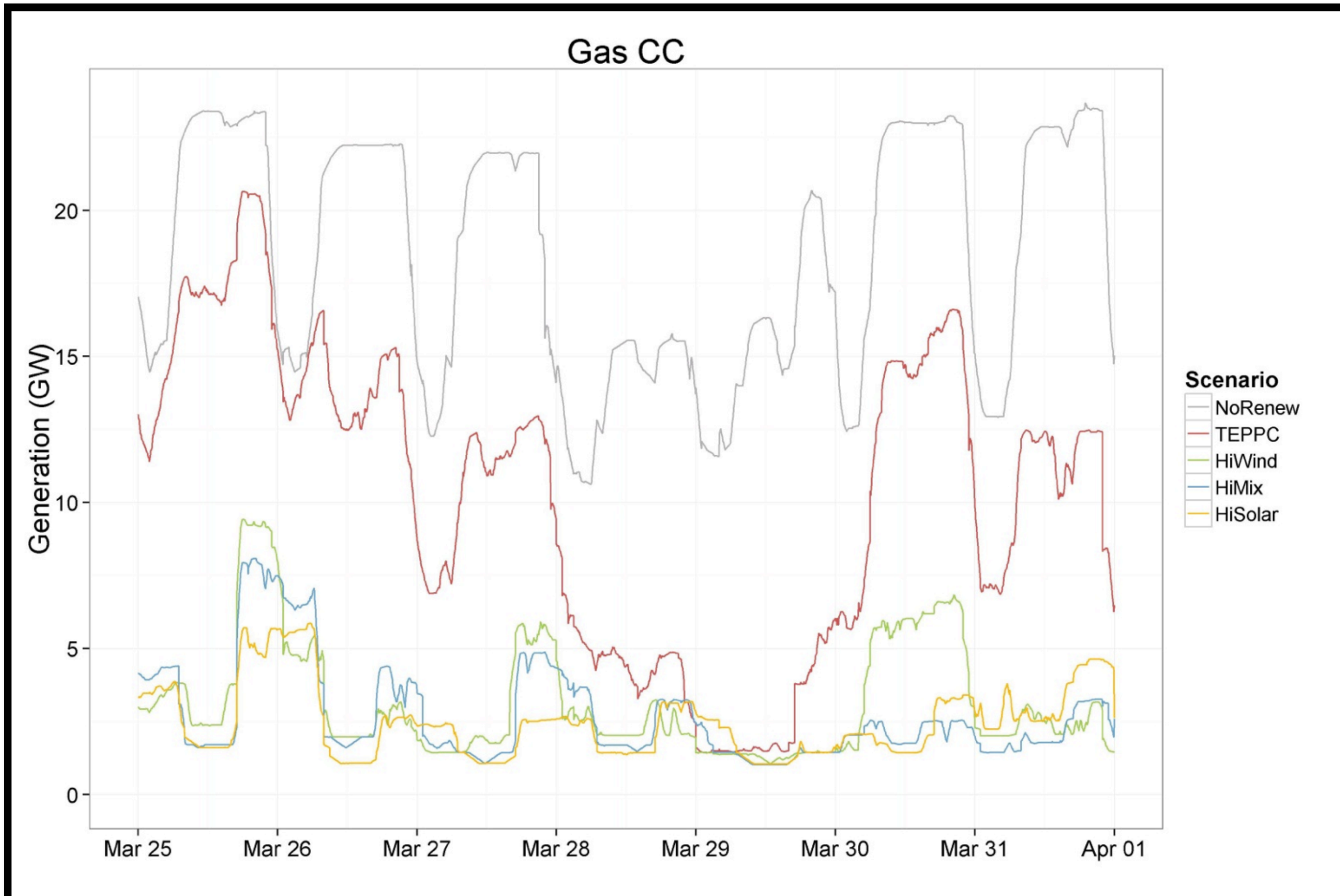
Gas CC - Summer Dispatch

CCs used similarly in all cases (but less in the high-renewable cases)



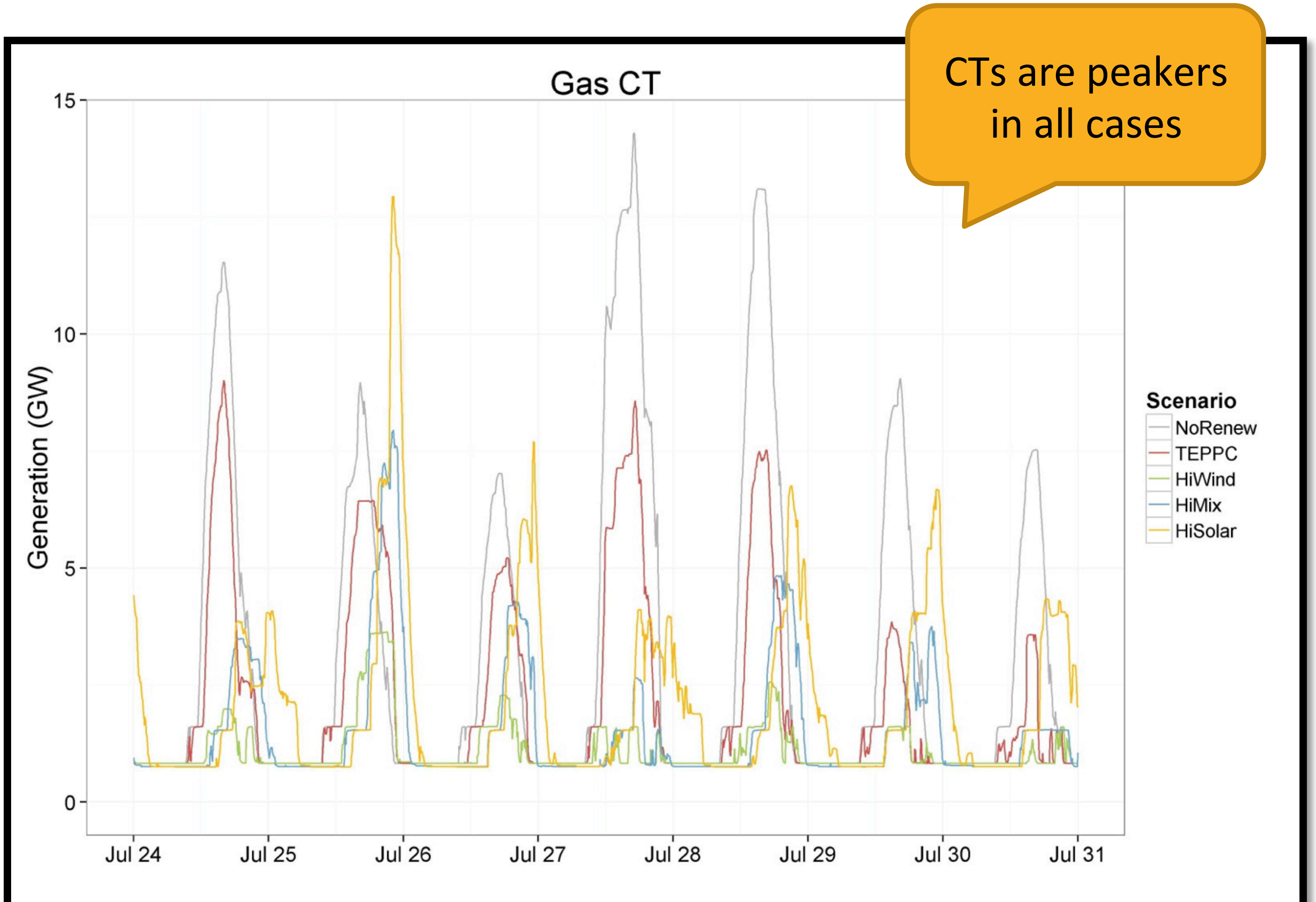
85-TimeGen_SummerGas CC

Gas CC - Spring Dispatch



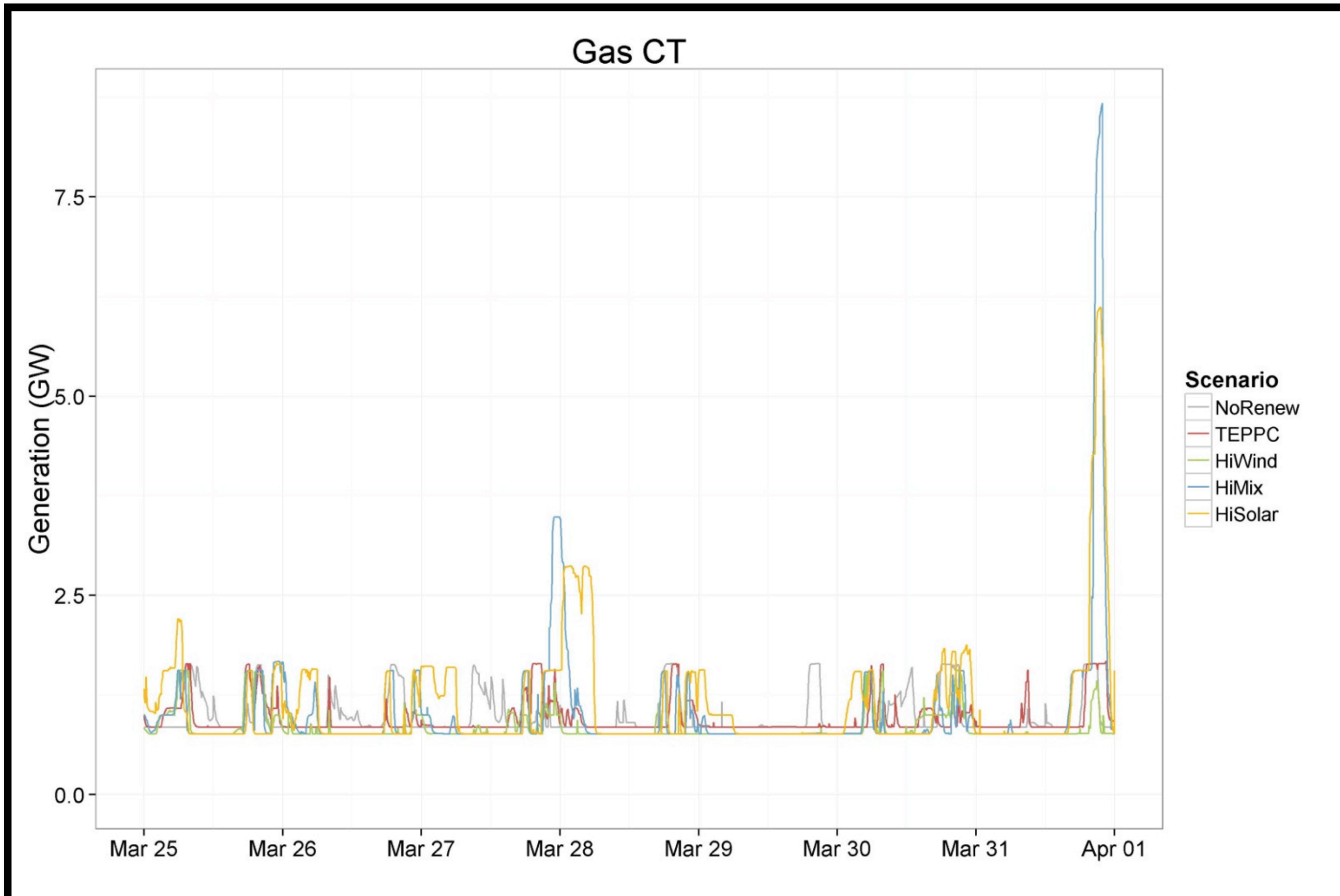
86-TimeGen_SpringGas CC

Gas CT - Summer Dispatch



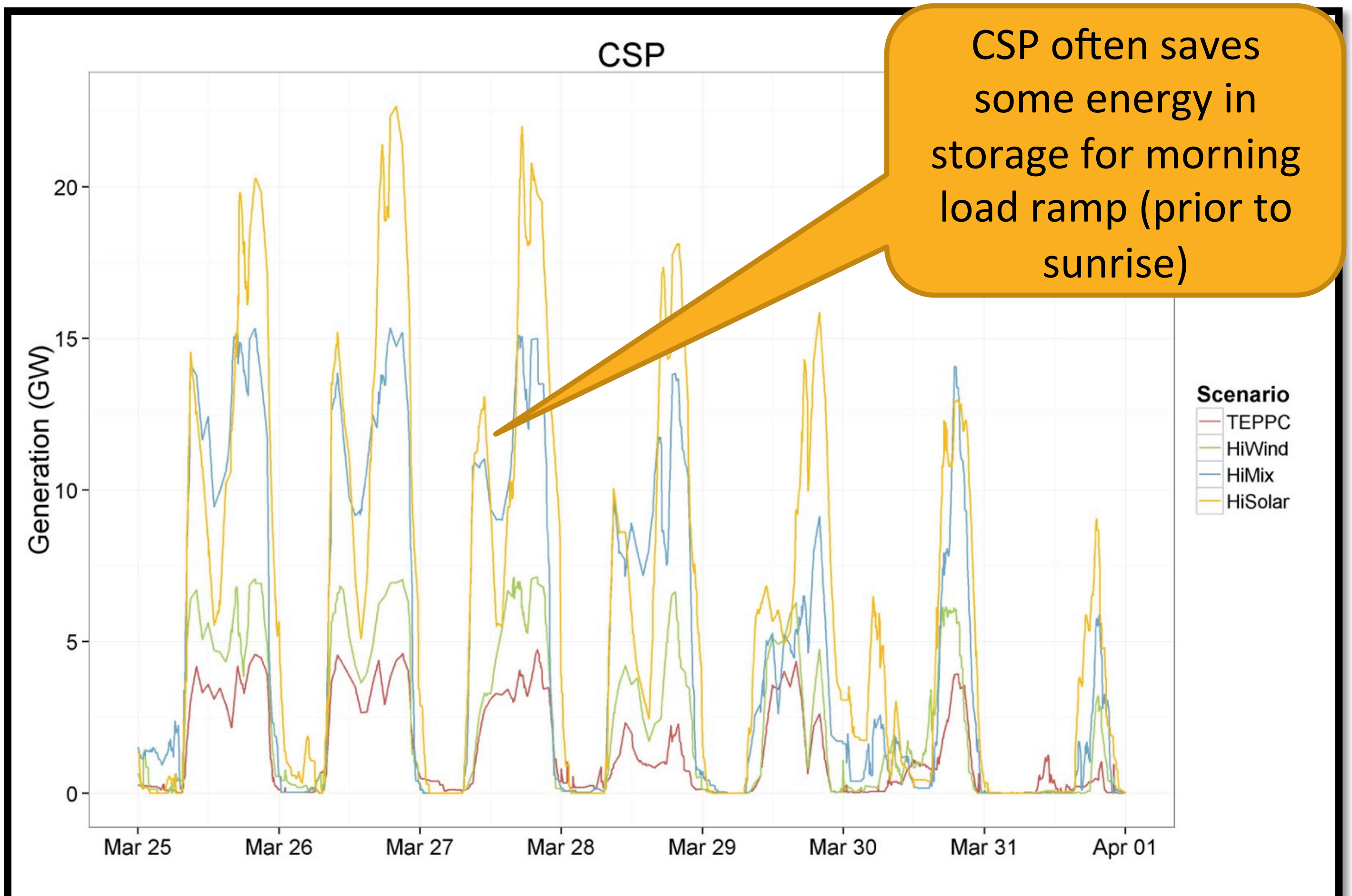
87-TimeGen_SummerGas CT

Gas CT - Spring Dispatch

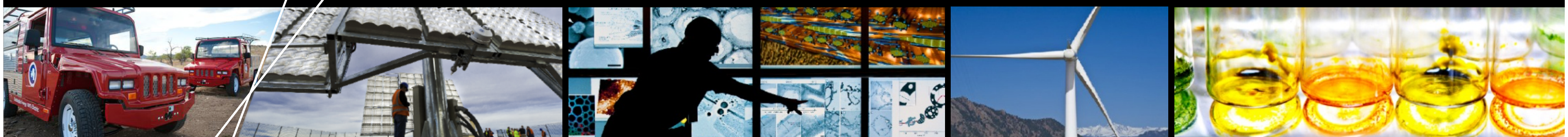


88-TimeGen_SpringGas CT

Spring Dispatch

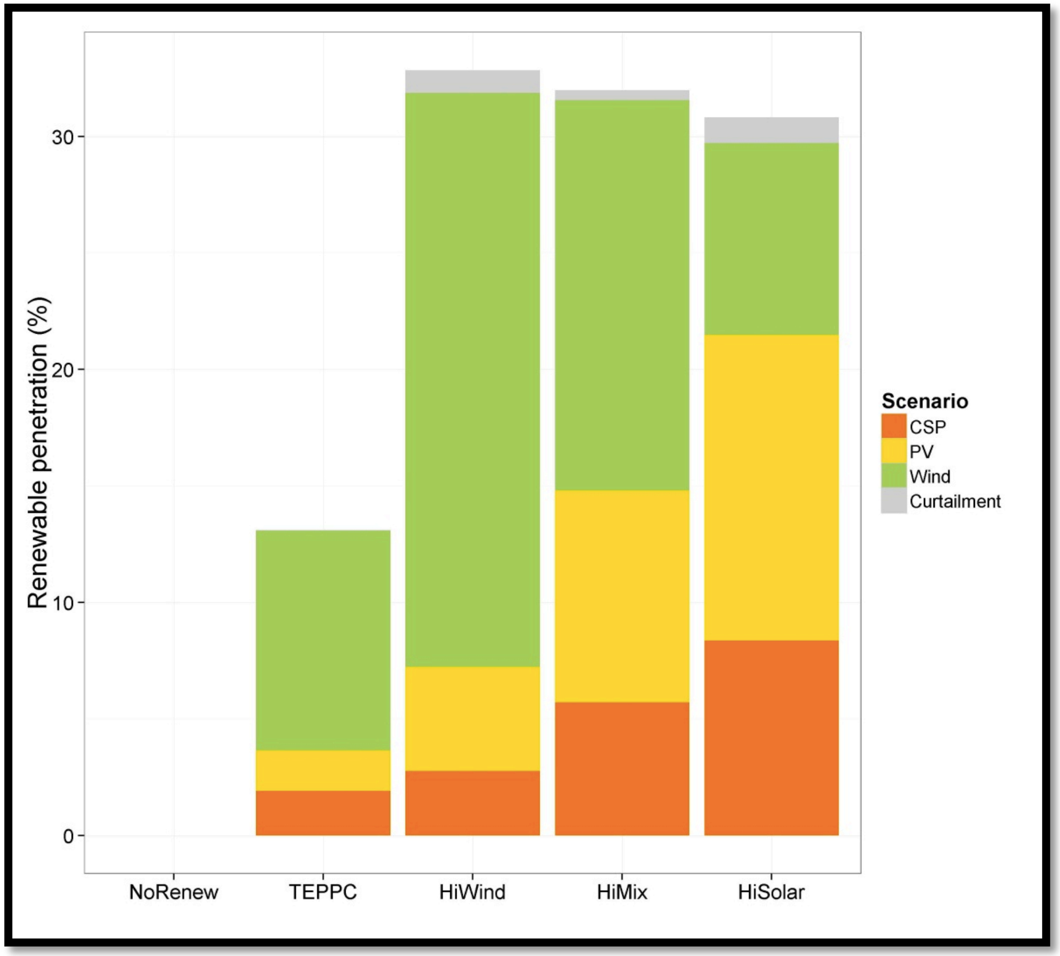


89-TimeGen_SpringCSP



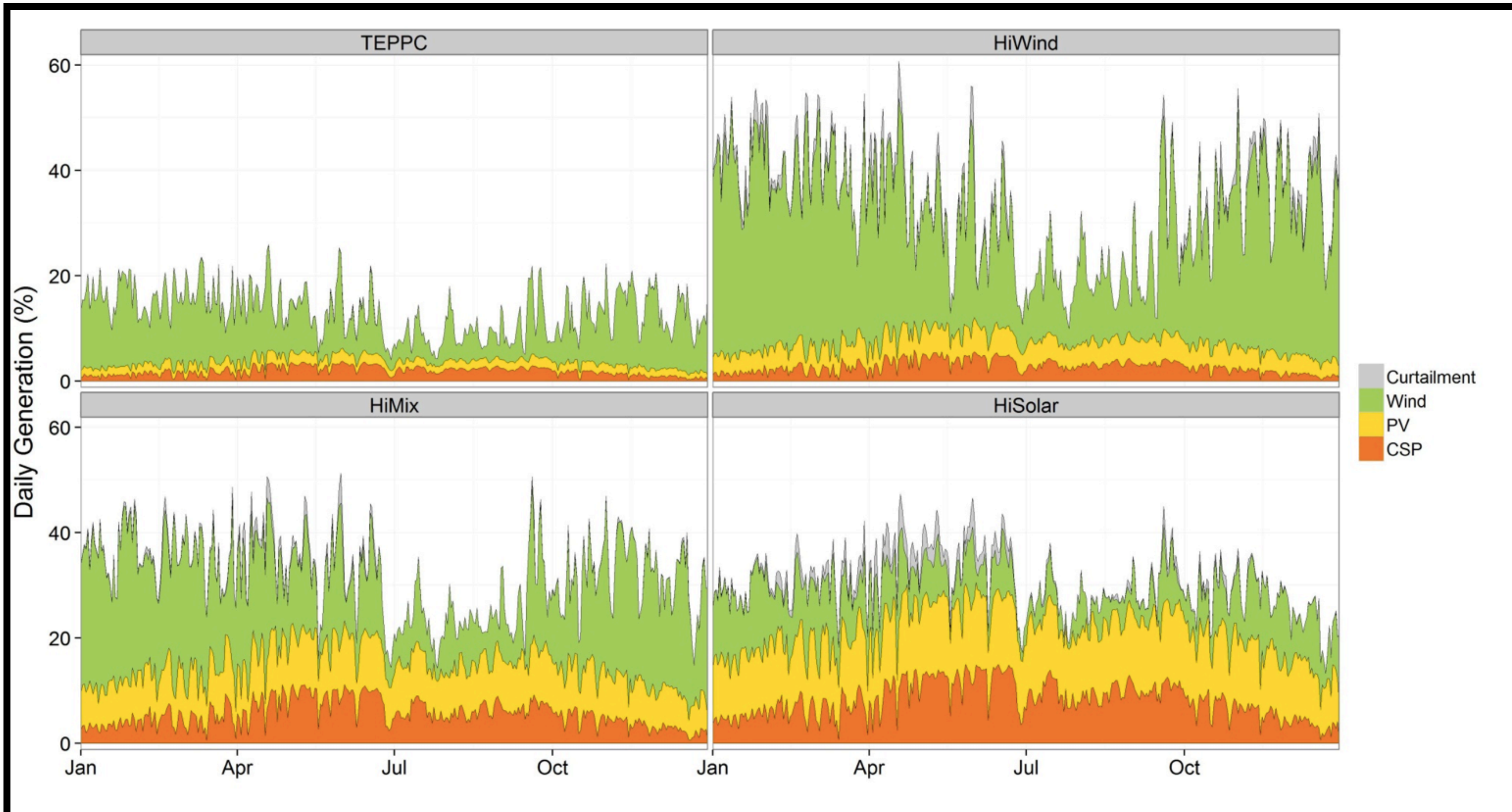
Results - penetration

Annual penetration



90-Penetration

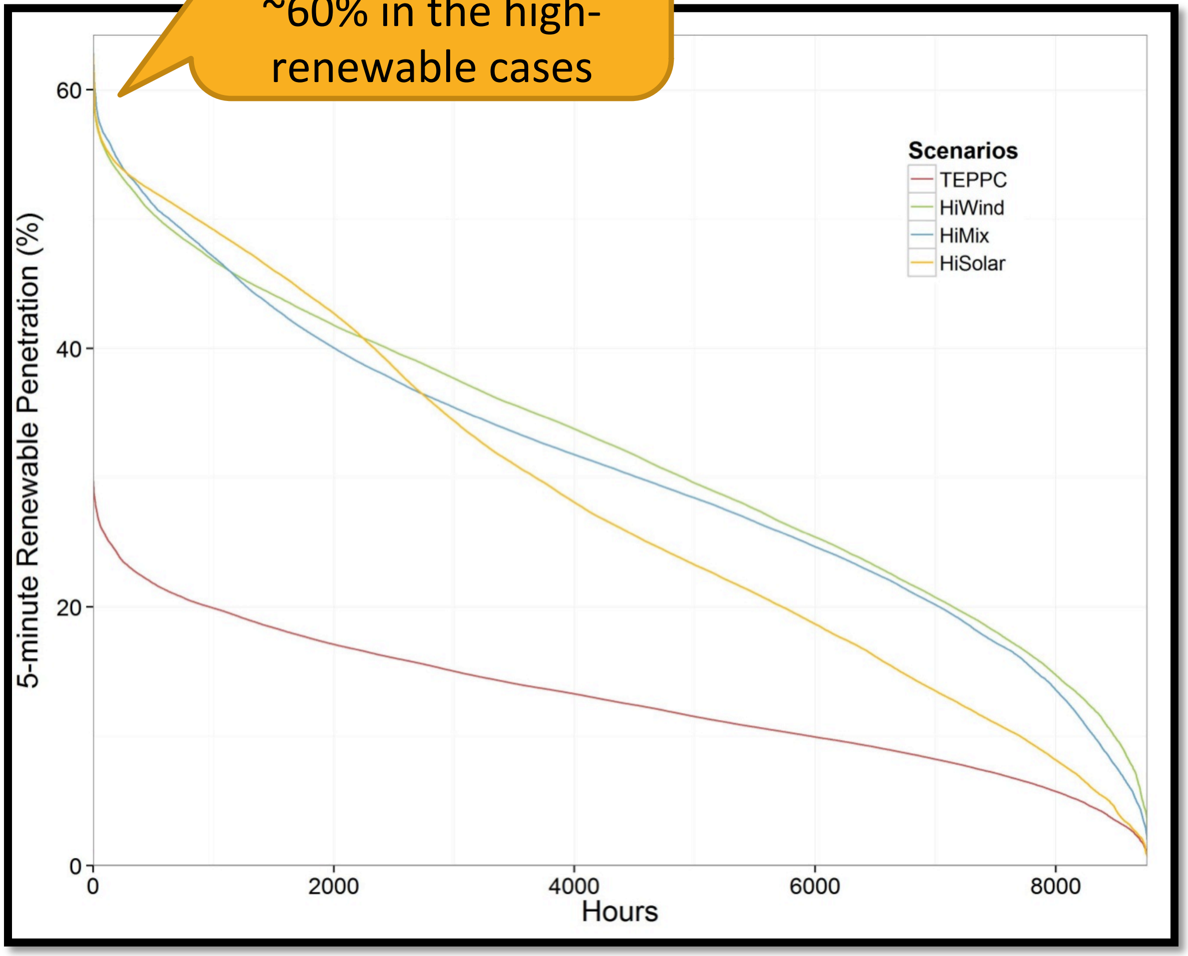
Daily renewable penetration



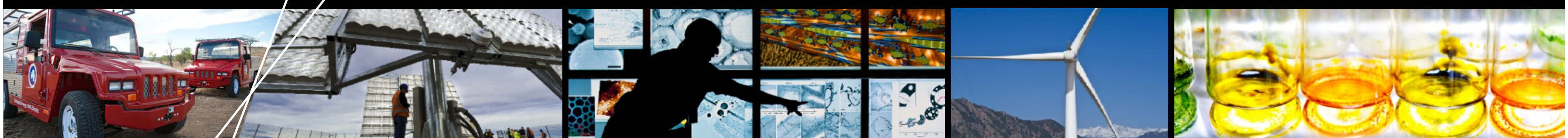
Penetration-daily-perc

Renewable penetration duration curve

Instantaneous penetrations peak at ~60% in the high-renewable cases

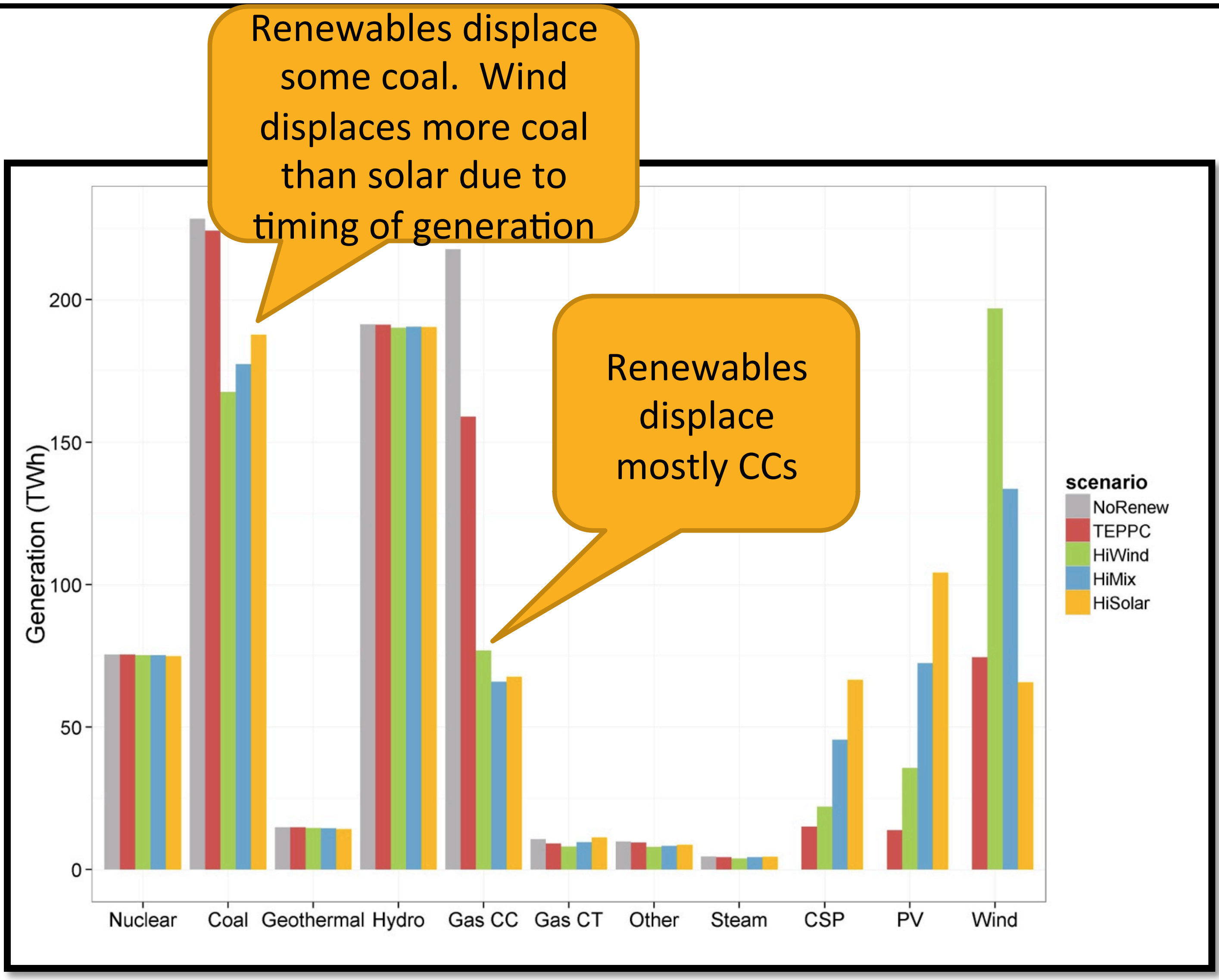


Penetration-duration



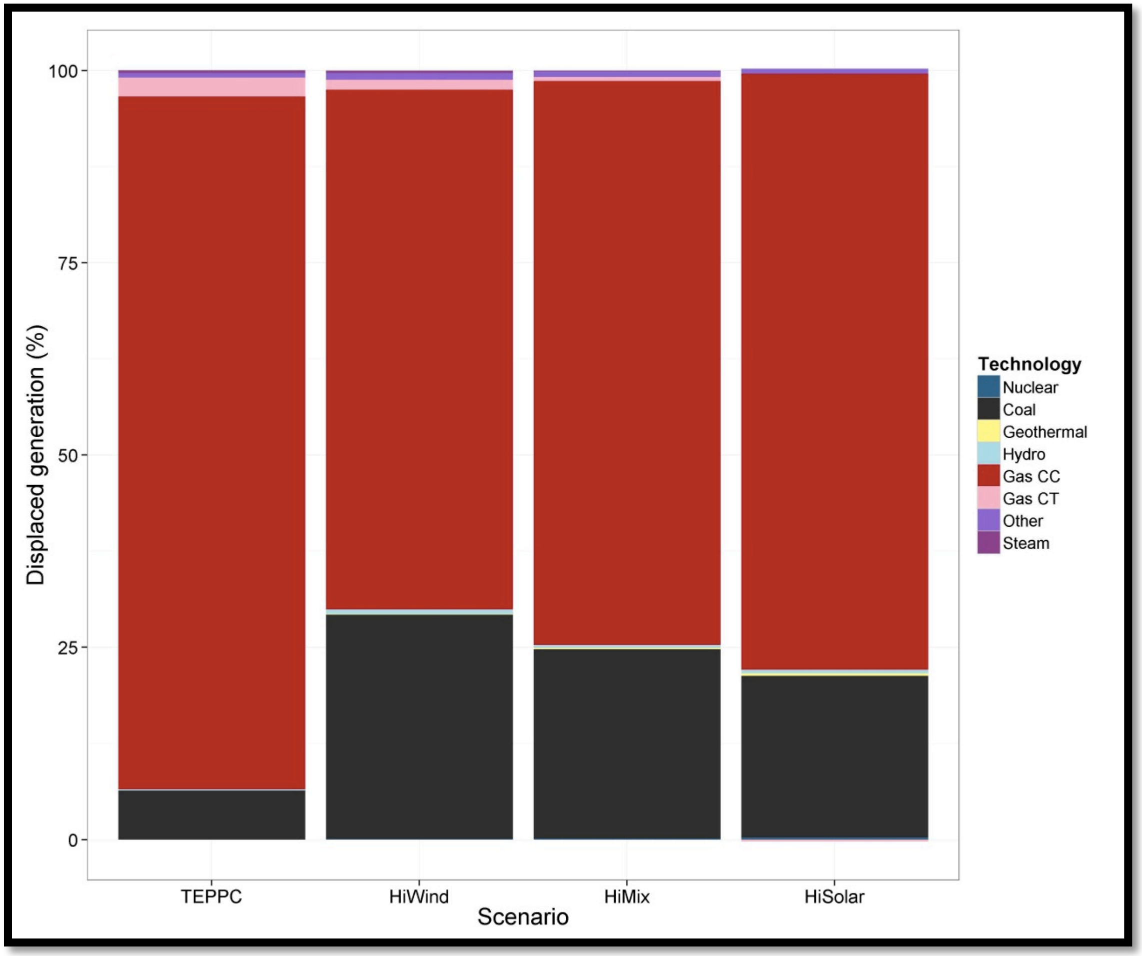
Results – generation by type

Generation by unit type

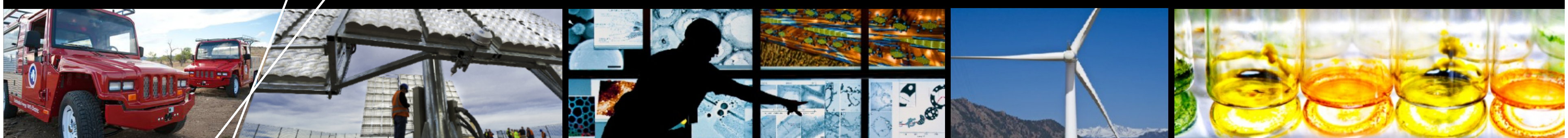


91-Generation-by-type

Displaced generation

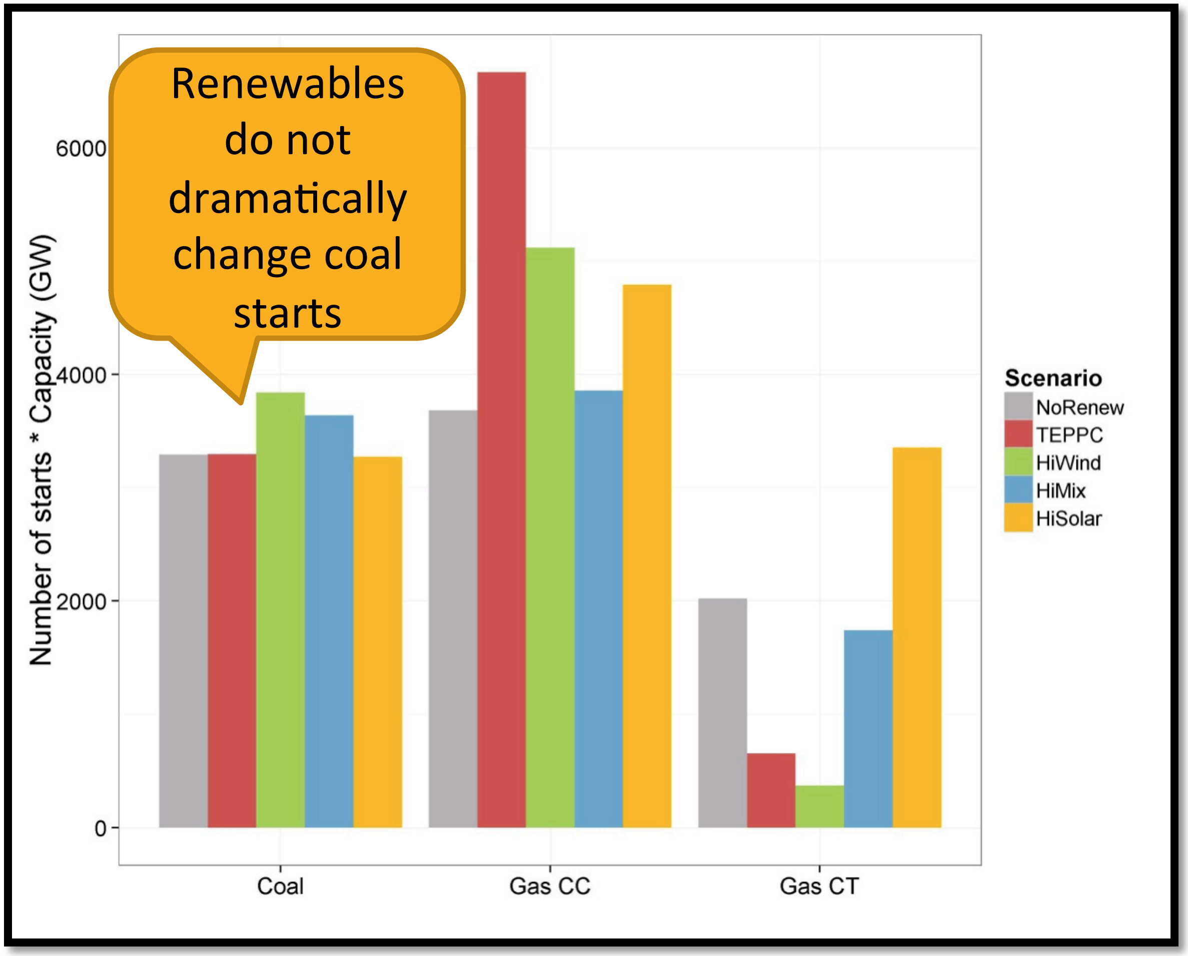


92-Generation-displaced-perc



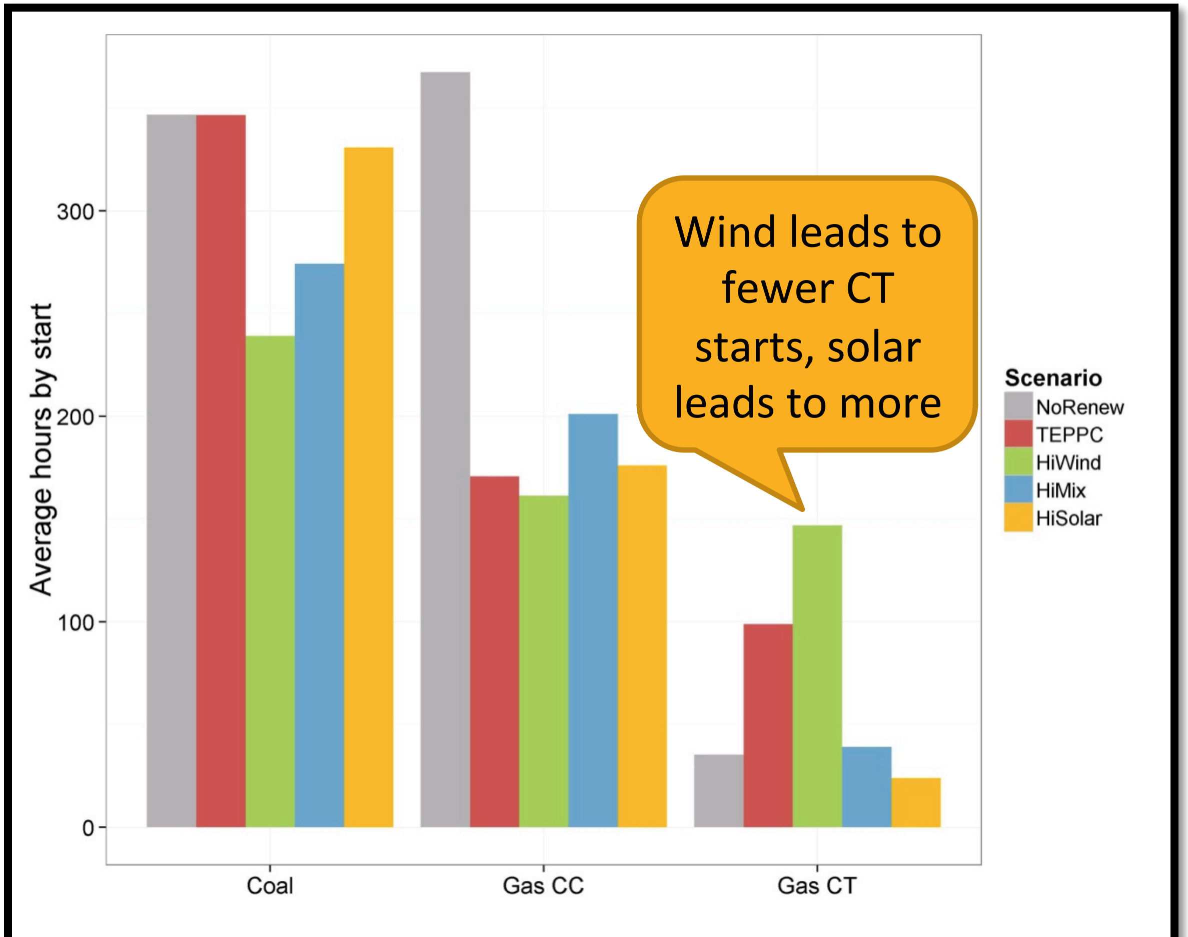
Results – cycling/ramping

Startups



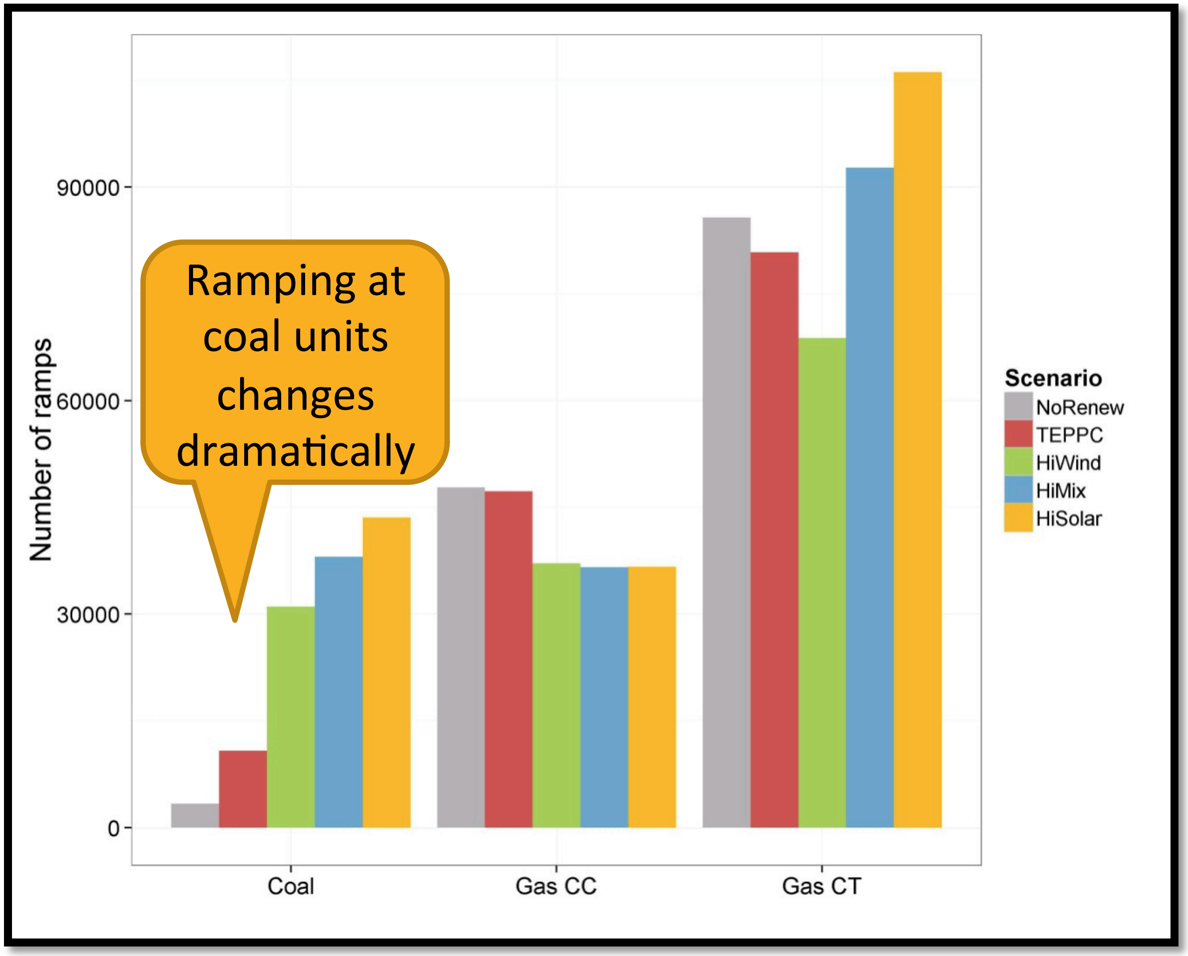
93-Starts-MW-by-type

Hours of operation per start



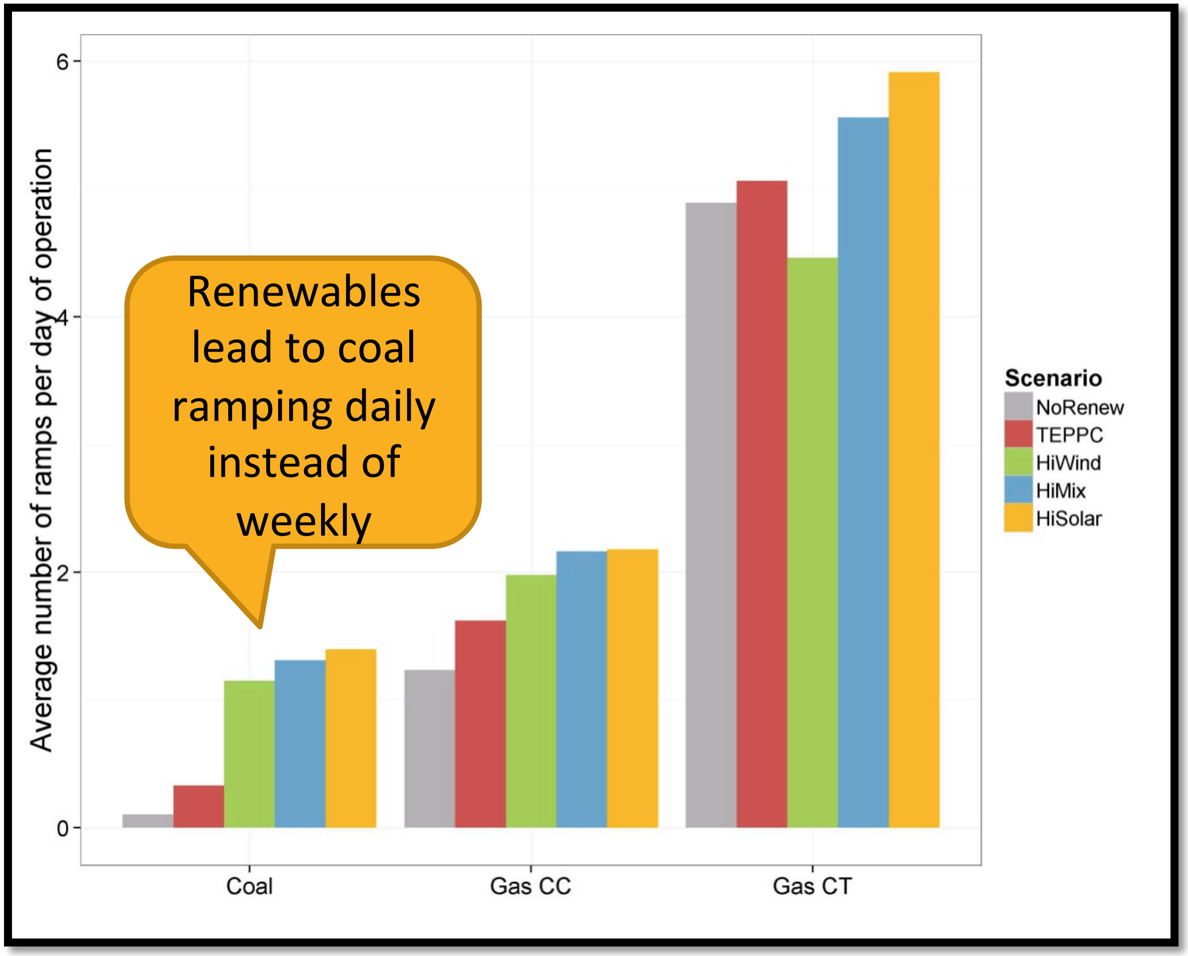
94-Starts-Hours-by-type

Number of load following ramps

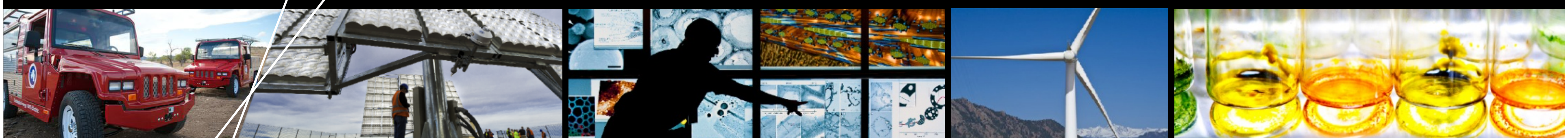


95-Ramps-by-type

Number of ramps per day of operation

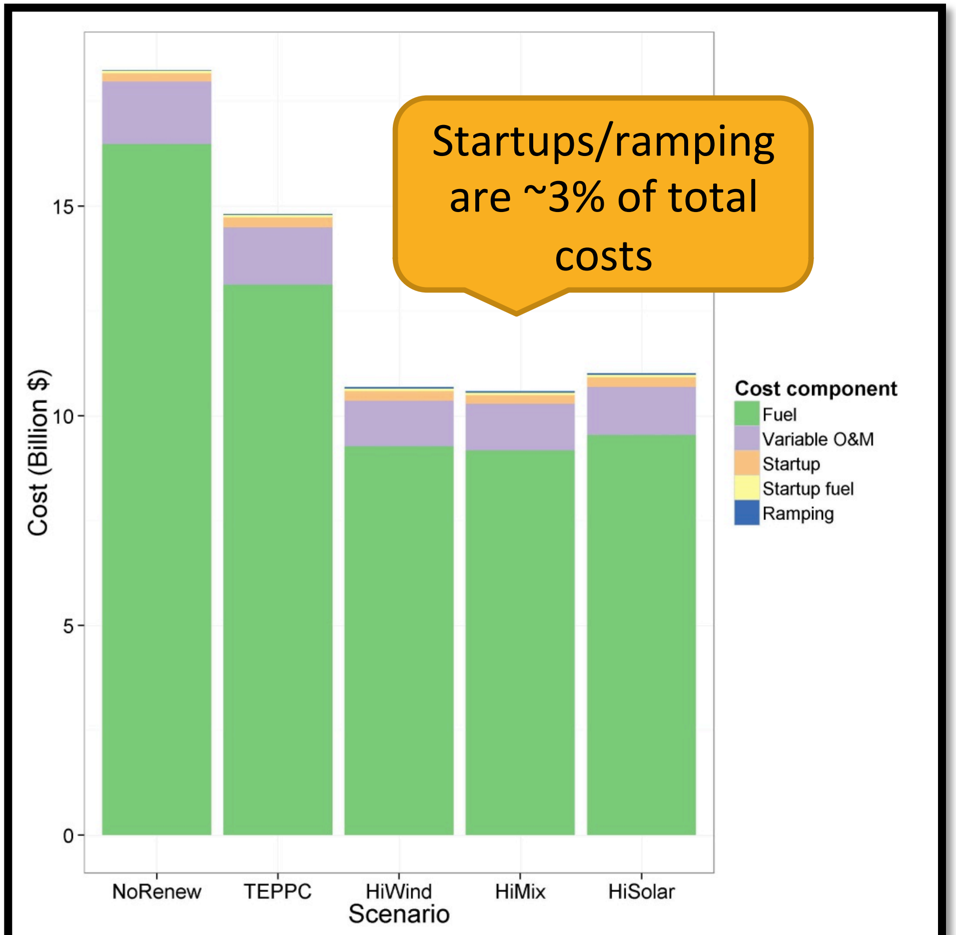


96-Ramps-Day-by-type



Results – production cost

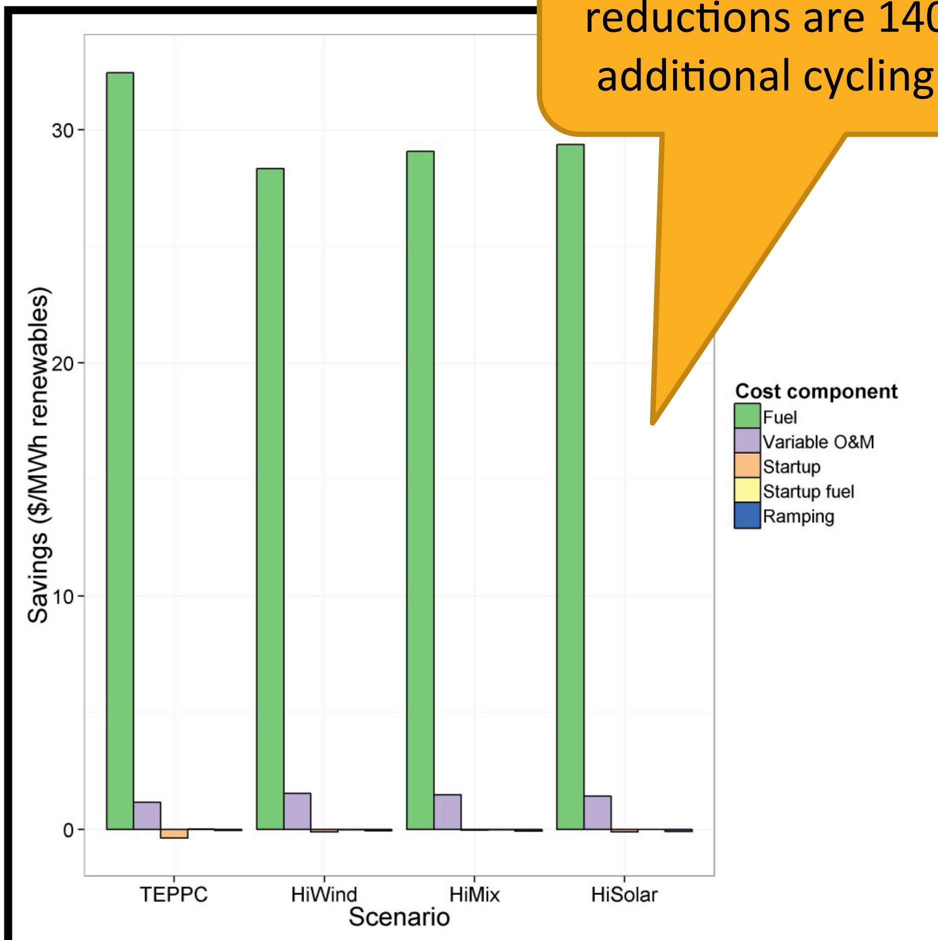
Total system production cost



97-total-cost

Production cost savings per MWh renewables

Wind/solar production cost reductions are 140-200 times the additional cycling costs incurred



98-total-cost-ratio

Cycling and ramping costs

Scenario	Cycling and ramping costs	Cycling and ramping costs as a fraction of total production cost	Increase in cycling and ramping cost as a fraction of renewable generation savings
No Renewables	$271 million	1.5%	—
TEPPC	$313 million	2.1%	1.2%
High Wind	$321 million	3.0%	0.7%
High Mix	$306 million	2.8%	0.5%
High Solar	$324 million	2.9%	0.7%

Startup cost sensitivities

- Cases were optimized with zero startup cost, lower bound median, and upper bound median
- Dispatch between zero startup cost and lower bound median were similar
- Upper bound median would have required a longer UC window to justify starting high-start-cost units (e.g., coal)
- Results presented are for upper bound start costs superimposed on lower bound dispatch

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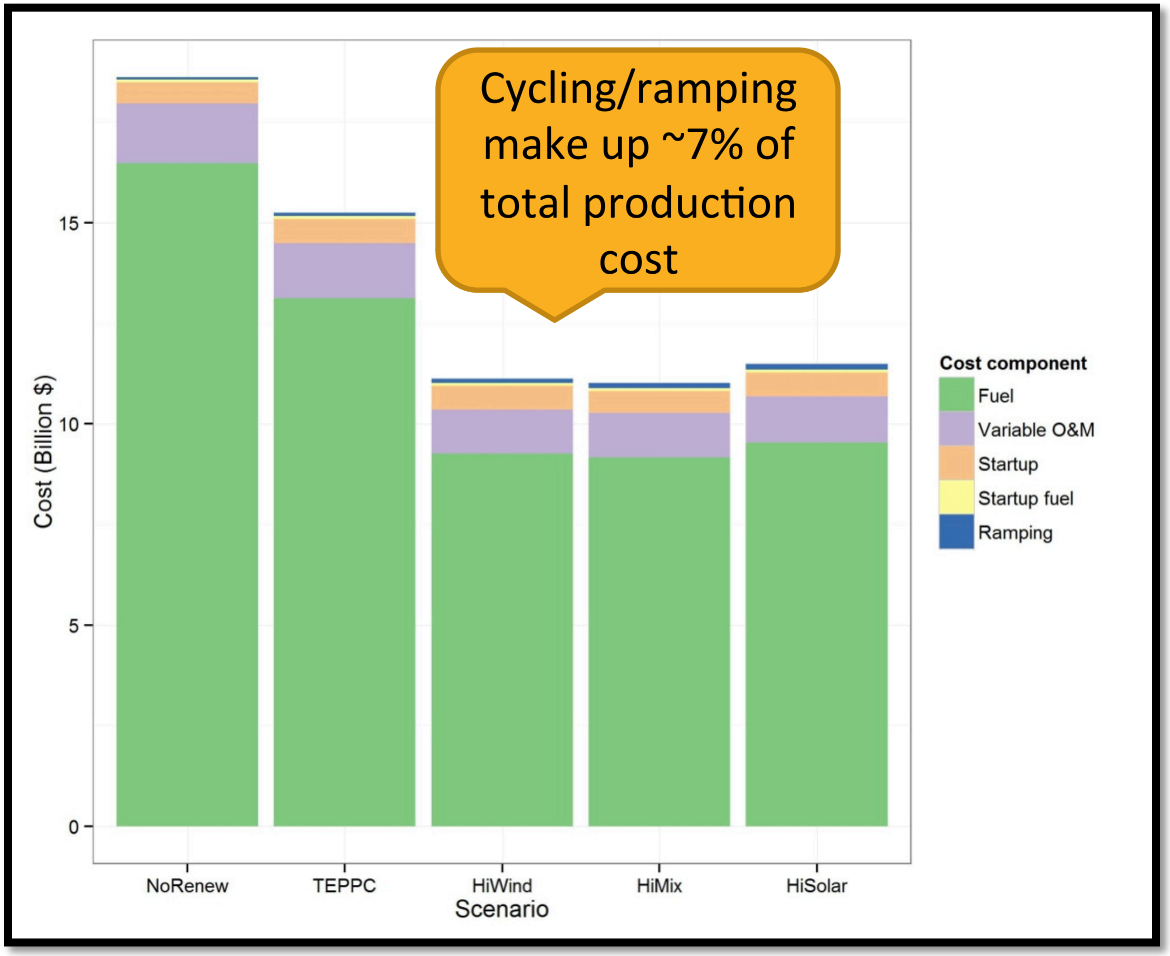
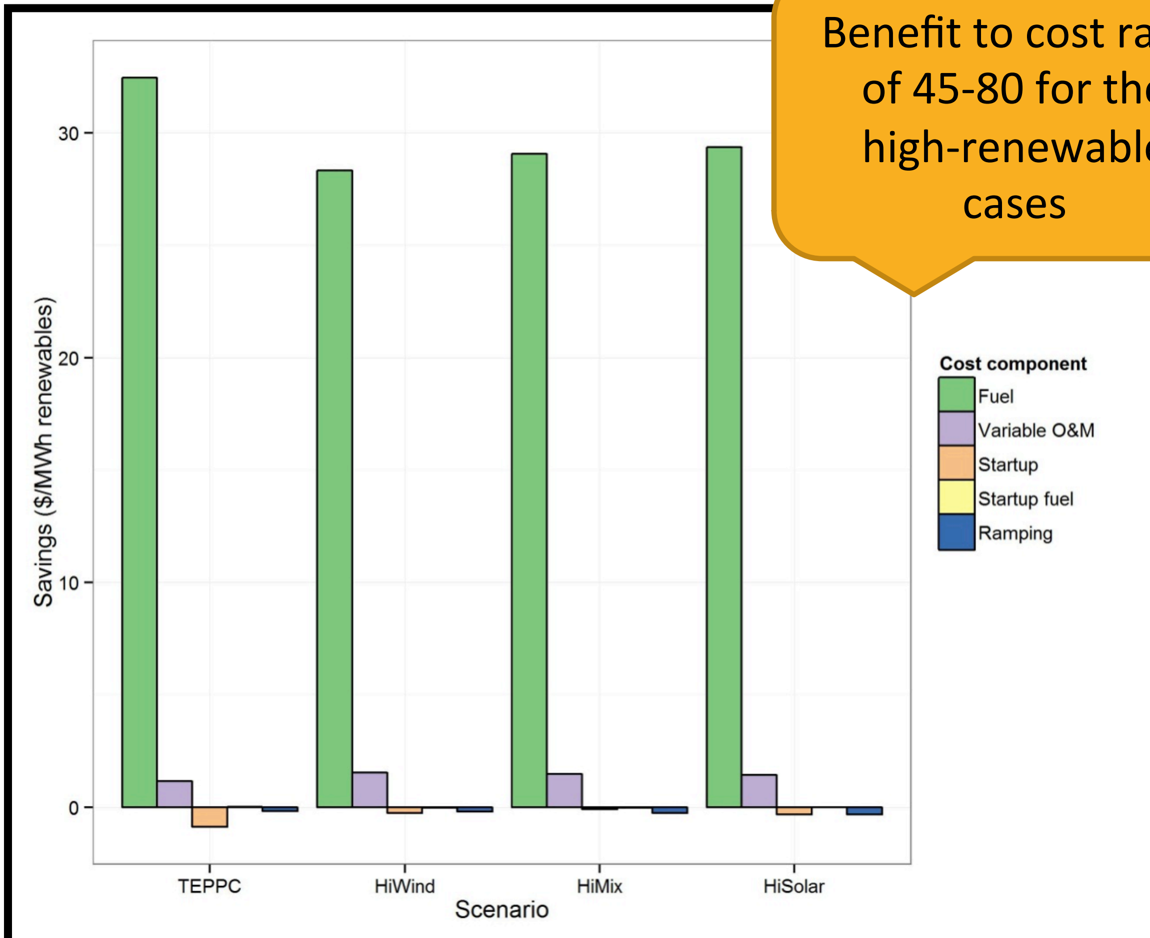
Upper bound - Total system production cost



99-total-ub-cost

Upper bound – Production cost savings per MWh renewables



Benefit to cost ratio of 45-80 for the high-renewable cases

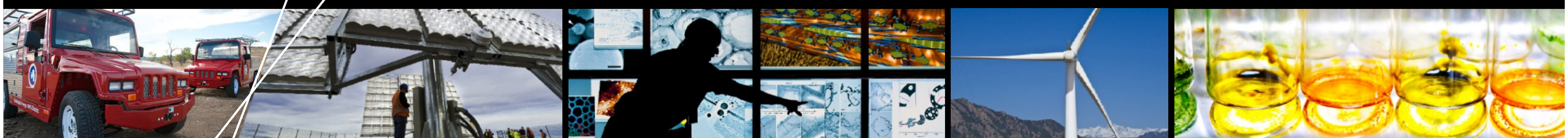
100-total-ub-cost-ratio

Upper bound – cycling and ramping costs

Scenario	Cycling and ramping costs	Cycling and ramping costs as a fraction of total production cost	Increase in cycling and ramping cost as a fraction of renewable generation savings
No Renewables	$643 million	3.5%	—
TEPPC	$751 million	4.9%	3.2%
High Wind	$769 million	6.9%	1.7%
High Mix	$738 million	6.7%	1.3%
High Solar	$800 million	7.0%	2.2%

3 ways to frame results…

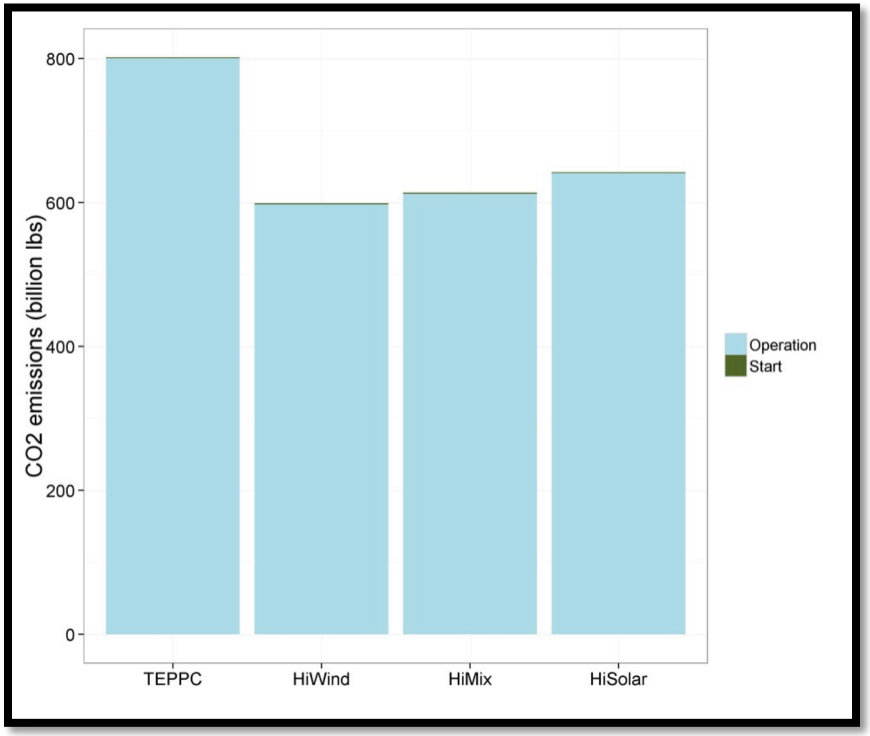
Startup and ramping costs make up approximately 3% of the total operating costs in the high renewable scenarios. Cycling- and ramping-related costs reduce the cost savings of renewable generation by approximately 0.5%-1.2%. In other words, the production cost reduction due to reduced fuel usage and variable O&M is 140-200 times (45-80 in upper bound analysis) larger than the increased costs due to cycling and ramping that was cause by increased renewable penetration in the high renewable scenarios. In the worst case scenario (the TEPPC Scenario with upper bound start costs), the startup and ramping costs reduced the value of renewables by less than $1/MWh.



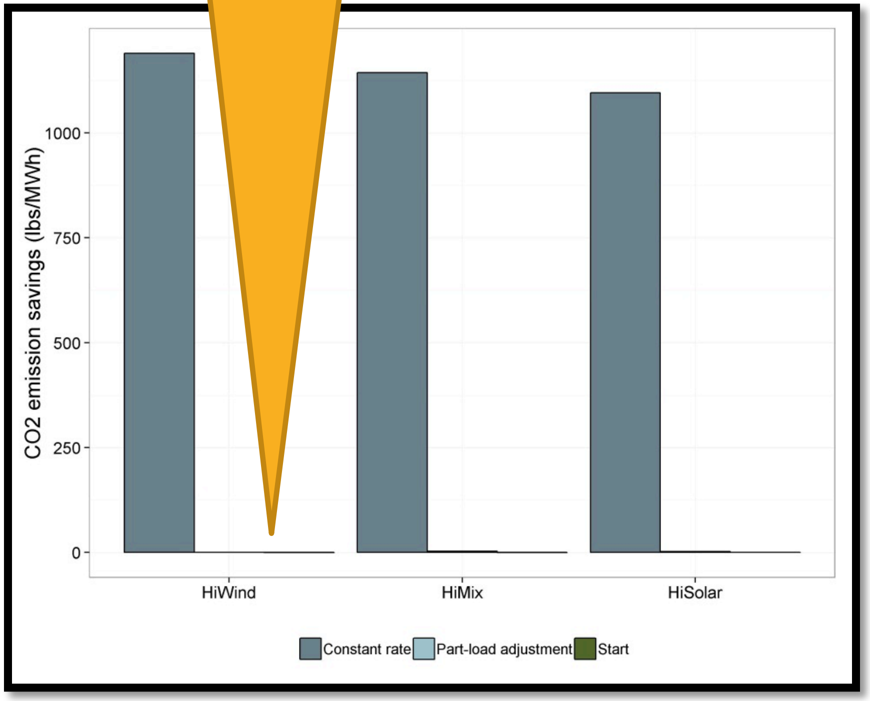
Results - emissions

CO2 emissions

Cycling/ramping impacts are negligible



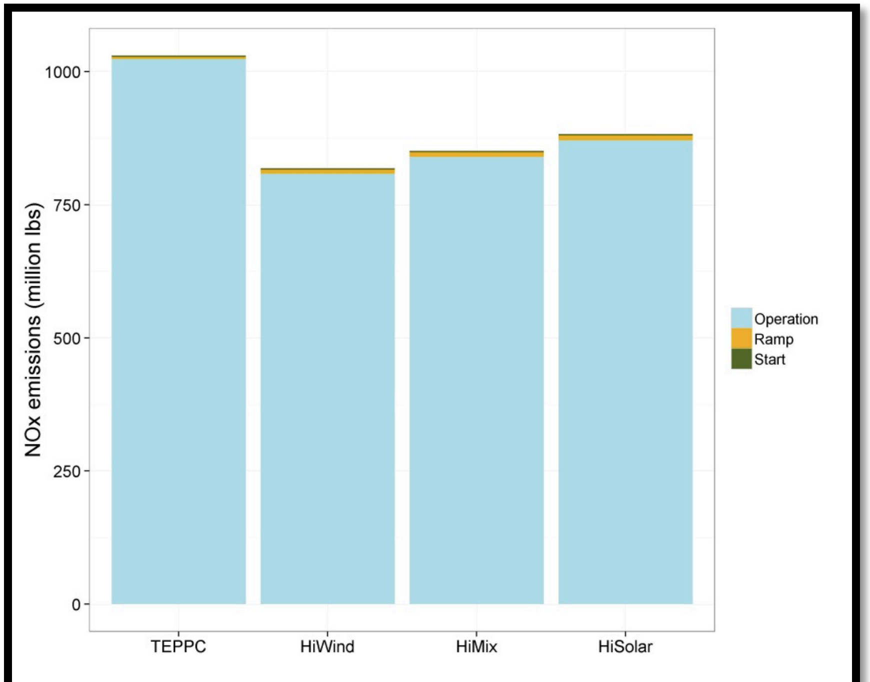
101a-Emiss-Total-CO2



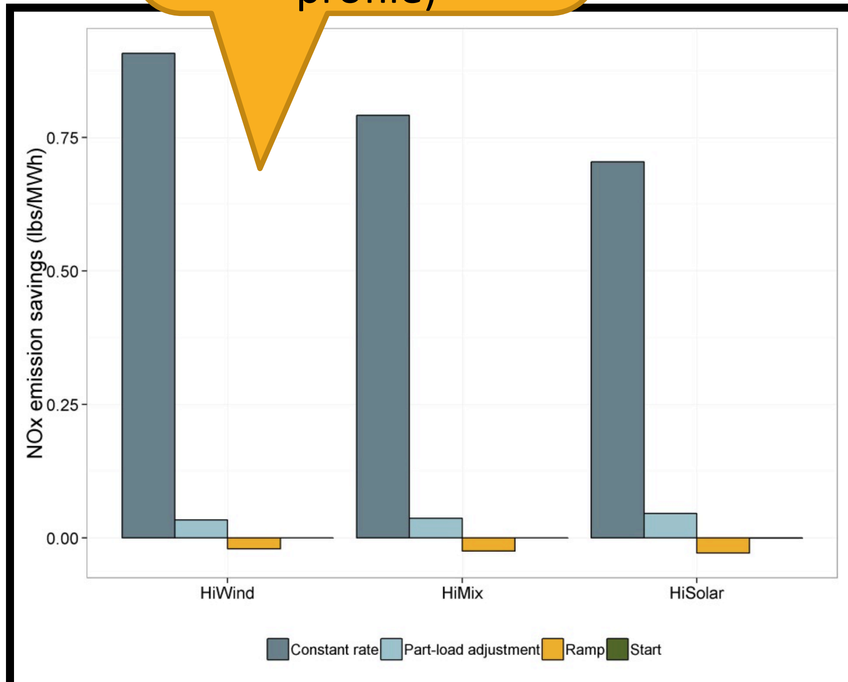
101b-Emiss-Delta-CO2

NOx emissions

Part-loading benefits NOx emissions (due to coal emissions profile)



102a-Emiss-Total-NOx

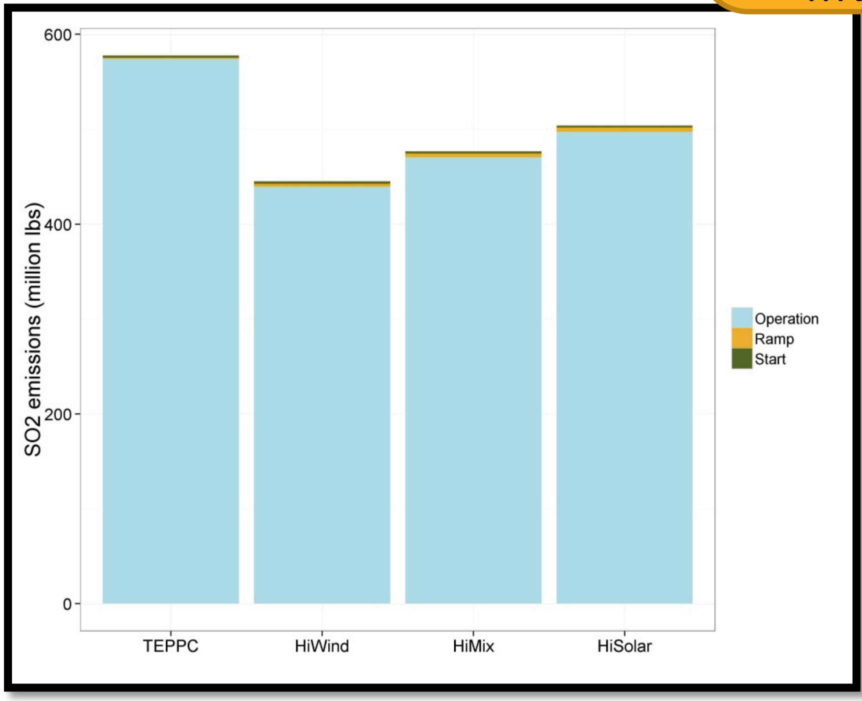


102b-Emiss-Delta-NOx

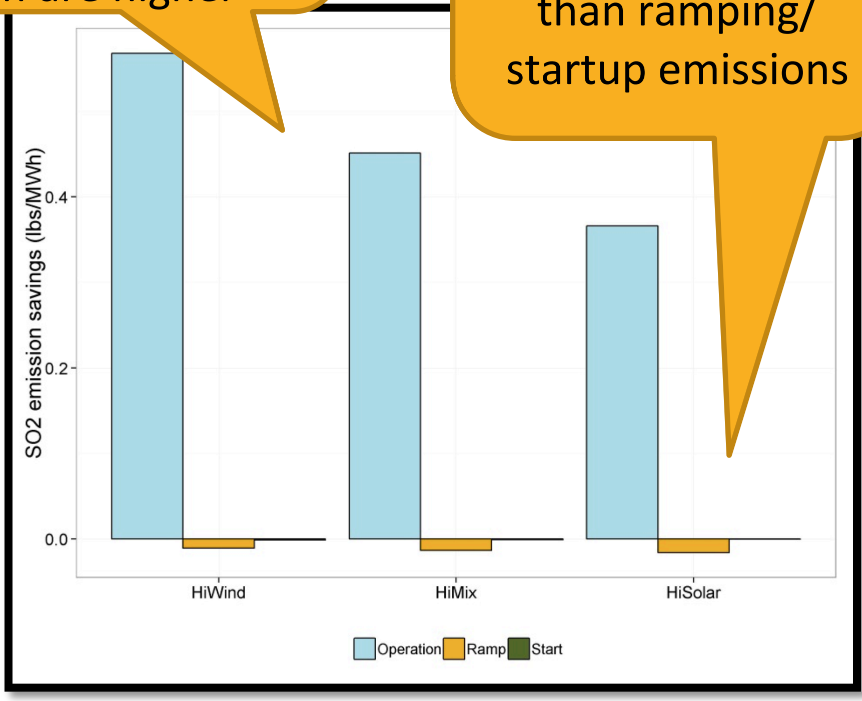
SO2 emissions

Wind reduces coal more than solar, therefore the emissions savings per MWh are higher

Worst-case scenario: benefits are 20 times larger than ramping/ startup emissions



103a-Emiss-Total-SO2



103b-Emiss-Delta-SO2

Emission impacts of renewables

Scenario	Avoided CO_2 (lbs/MWh)	Avoided NO_x (lbs/MWh)	Avoided SO_2 (lbs/MWh)
High Wind	1190	0.92	0.56
High Mix	1150	0.80	0.44
High Solar	1100	0.72	0.35

Scenario	WI-wide renewable penetration	CO_2 reduction	NO_x reduction	SO_2 reduction
High Wind	26.0%	33.5%	22.3%	24.1%
High Mix	25.7%	31.9%	19.2%	18.7%
High Solar	24.2%	28.8%	16.2%	14.1%

Emission impacts of cycling ramping

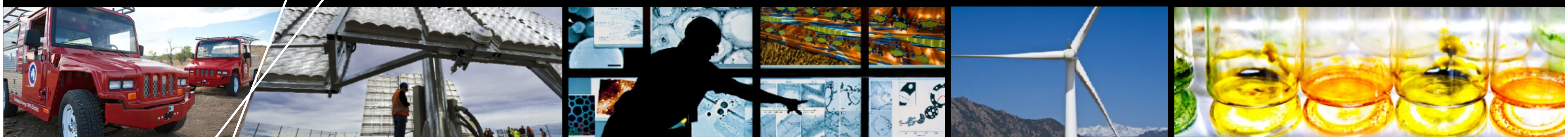
Pollutant	Scenario	Part-Load Impact	Ramping Impact	Start-Up Impact
CO_2	High Wind	0.0%	—	0.0%
CO_2	High Mix	+0.2%	—	0.0%
CO_2	High Solar	+0.2%	—	0.0%
NO_x	High Wind	+3.6%	-2.2%	0.0%
NO_x	High Mix	+4.6%	-3.1%	0.0%
NO_x	High Solar	+6.3%	-3.9%	-0.1%
SO_2	High Wind	—	-1.9%	-0.2%
SO_2	High Mix	—	-3.0%	-0.2%
SO_2	High Solar	—	-4.5%	0.0%

Percent change in emission benefit of renewables. E.g., if the SO2 emission impact (without considering ramping) was 1 lb/MWh, the ramping effect in the high solar case (-4.5%) would be 0.955 lb/MWh.

2 ways to frame results…

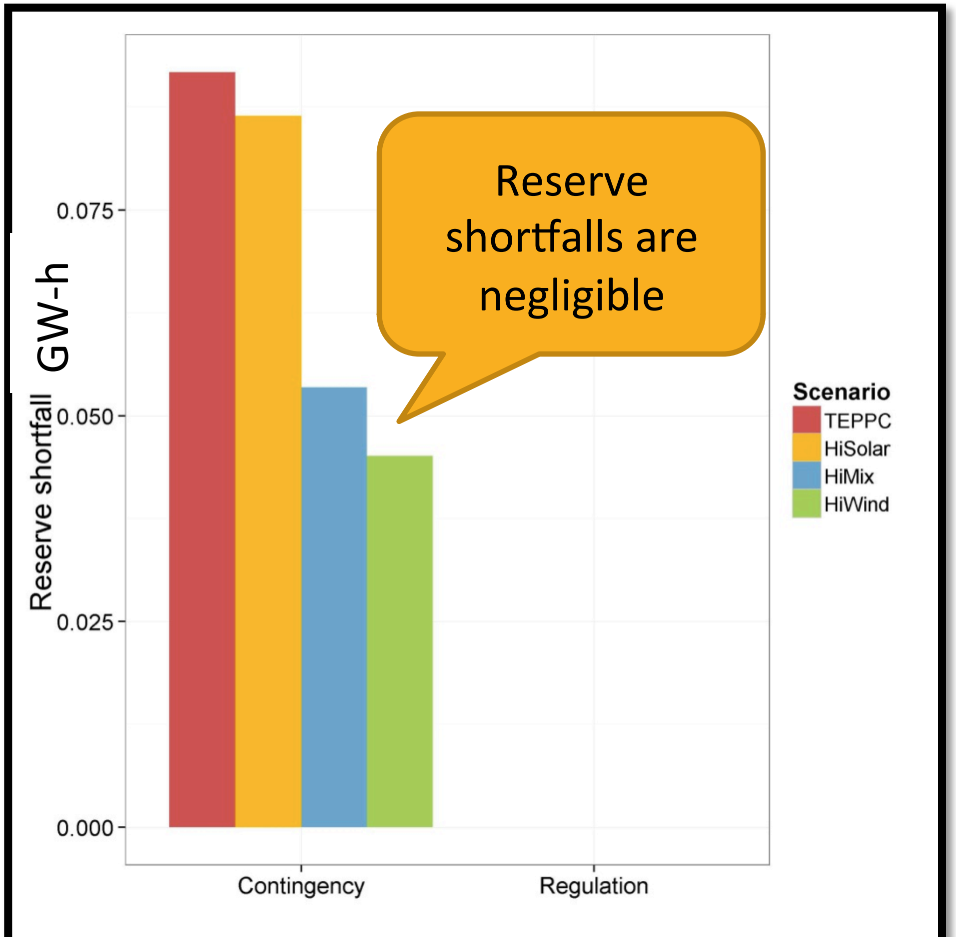
A 24-26% penetration of renewables throughout all of the WI (including Canada and Mexico) leads to a 29-34% reduction in CO_2, 16-22% reduction in NOx, and a 14-24% reduction in SO_2 system-wide…

Cycling and ramping impacts have a very small impact (less than 5%) on the avoided emissions of renewables. In other words, emissions benefits of wind and solar are at least 20 times larger than the emission penalties induced by cycling and ramping.



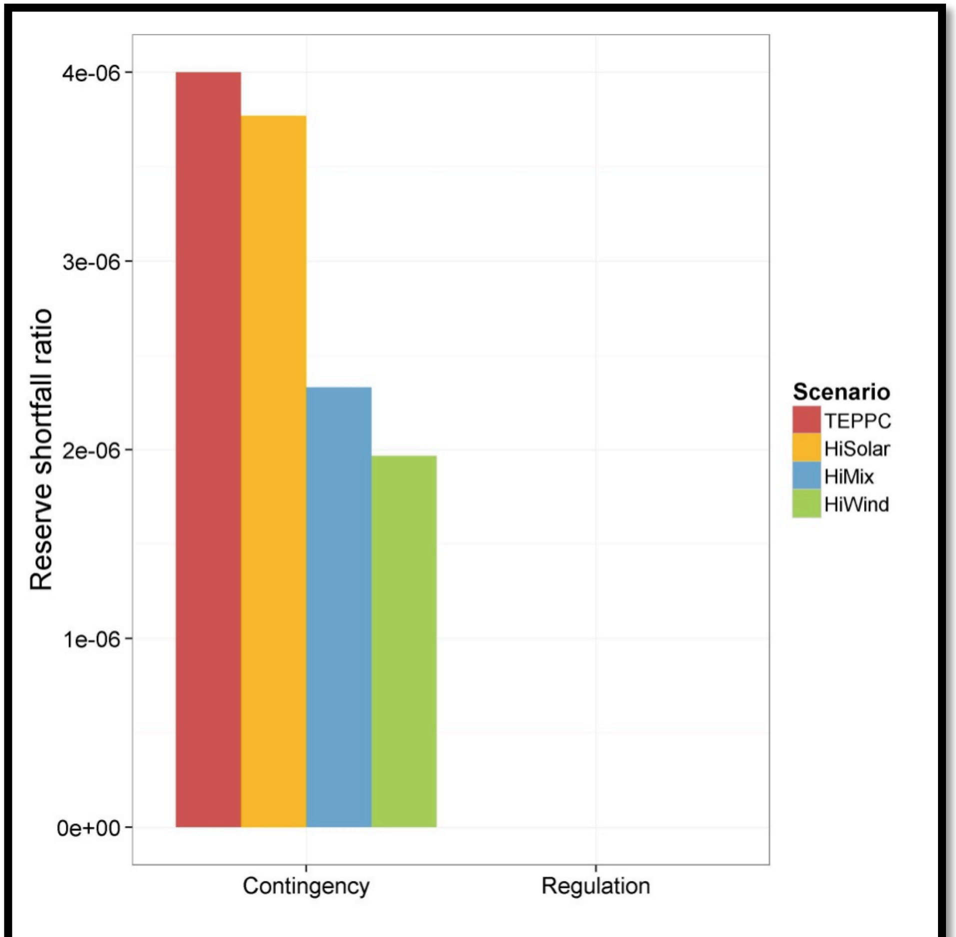
Results – reserve shortages

Reserve shortfalls (energy)

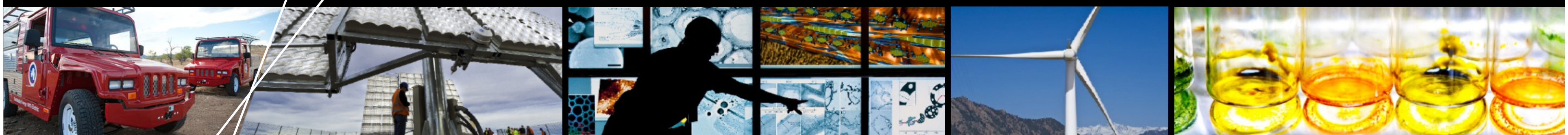


104-(optional)-ShortfallReserve-MWh

Reserve shortfall (fraction)

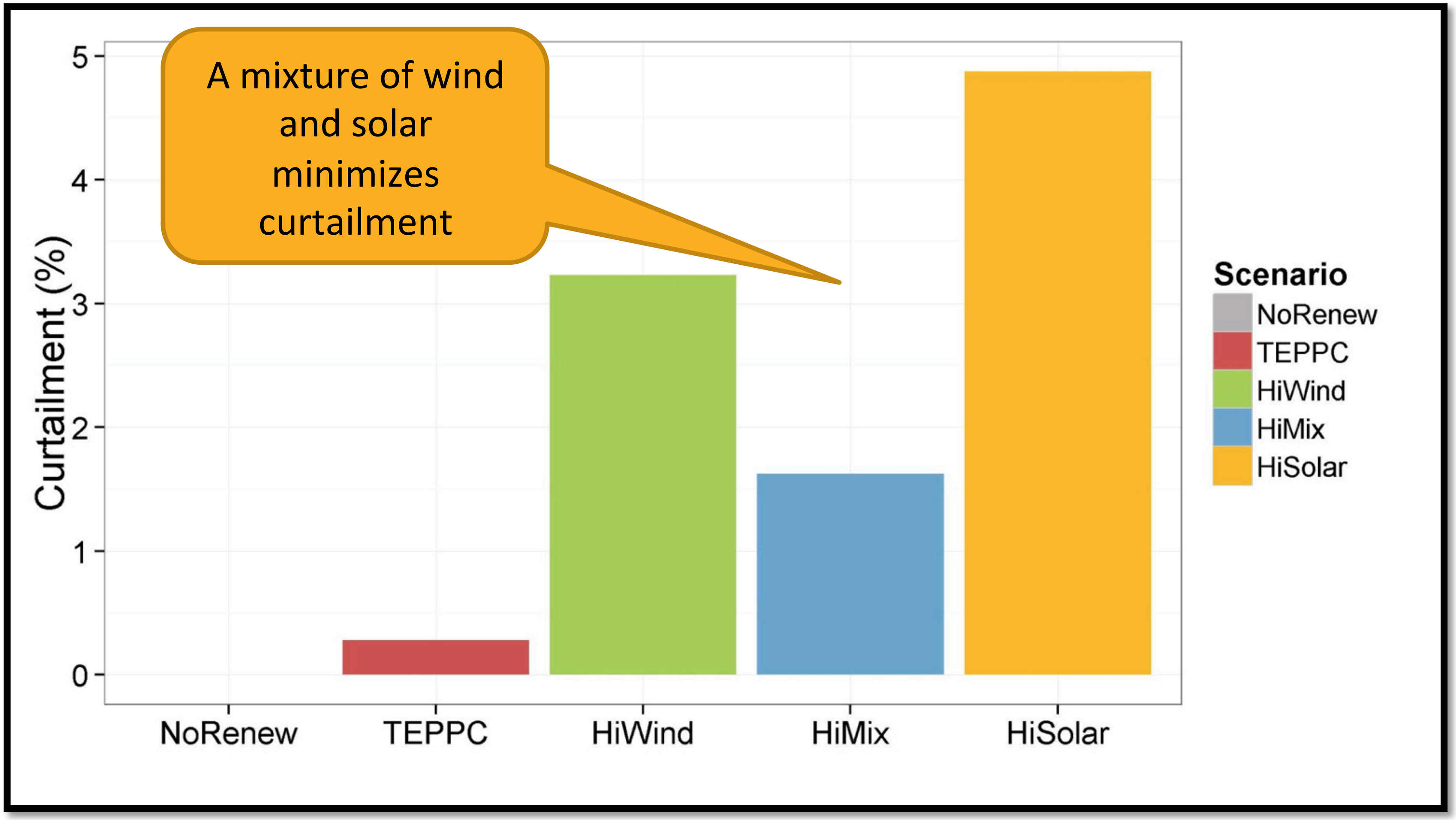


104-ShortfallReserve



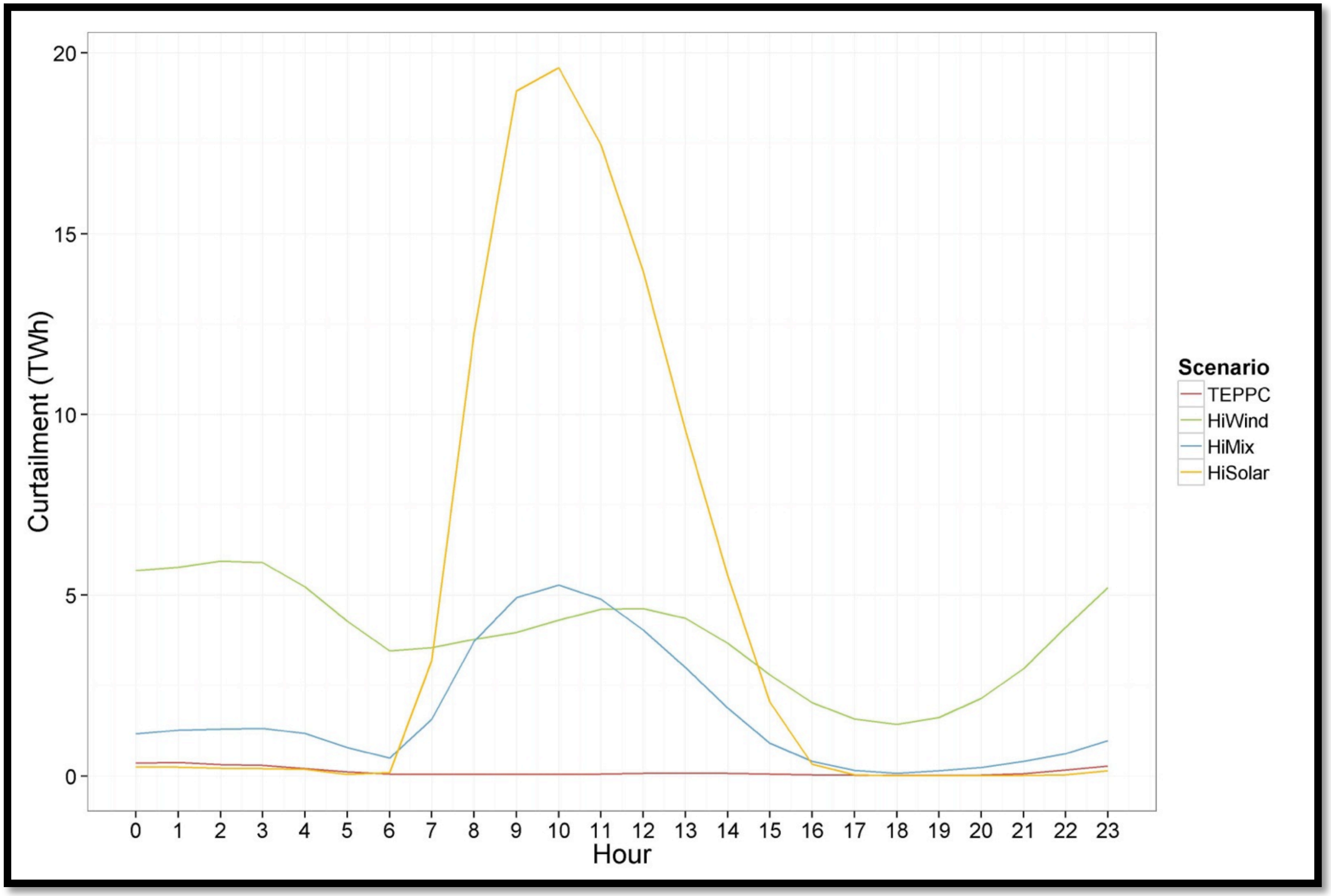
Results - curtailment

Curtailment by scenario



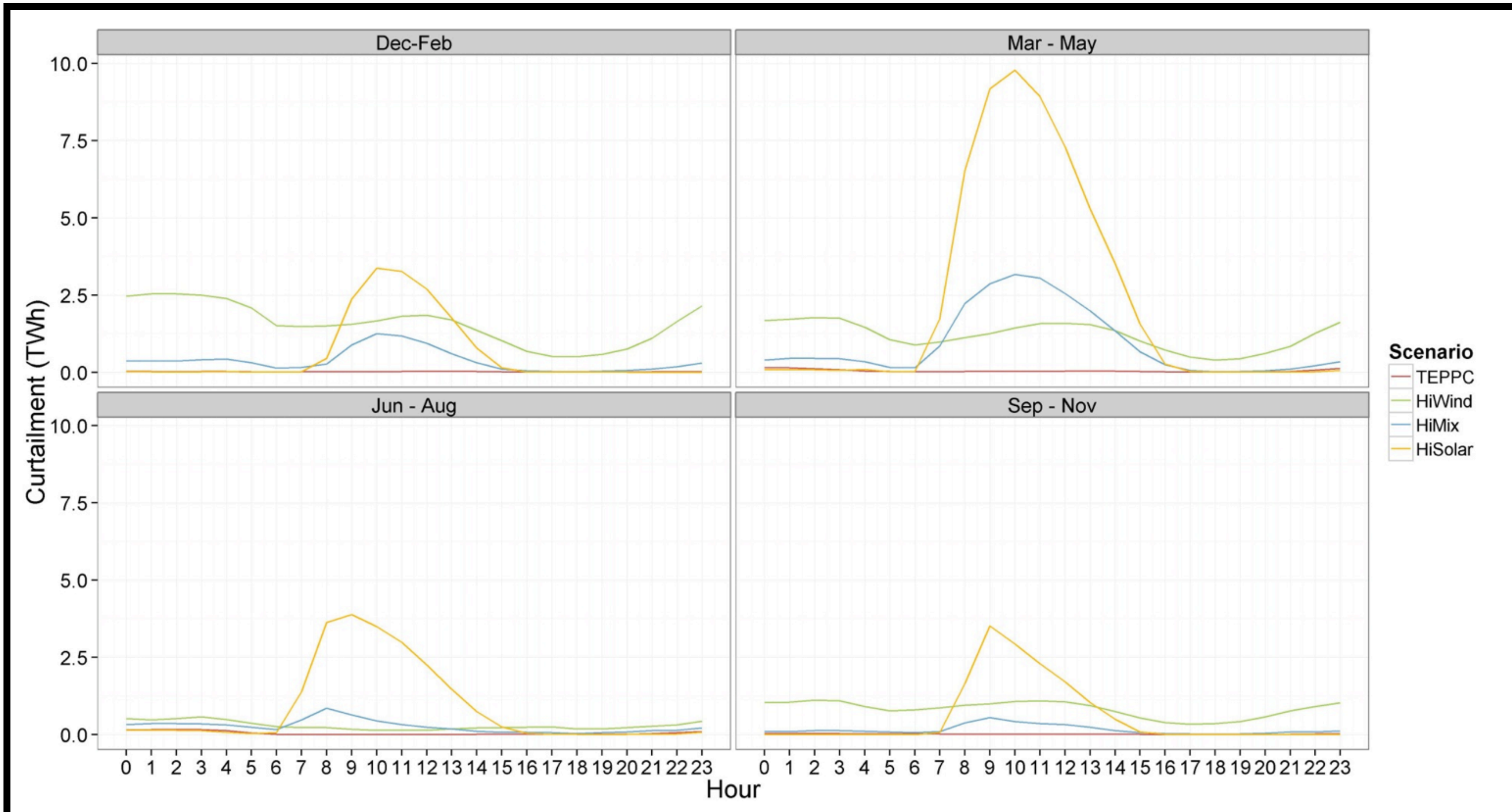
105-Curtailment-ratio

Curtailment by hour

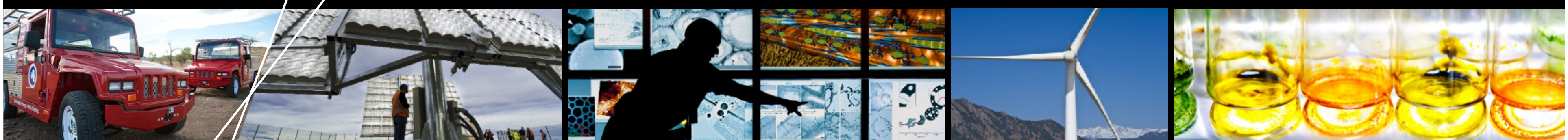


106-Curtailment-hour

Curtailment by hour by season

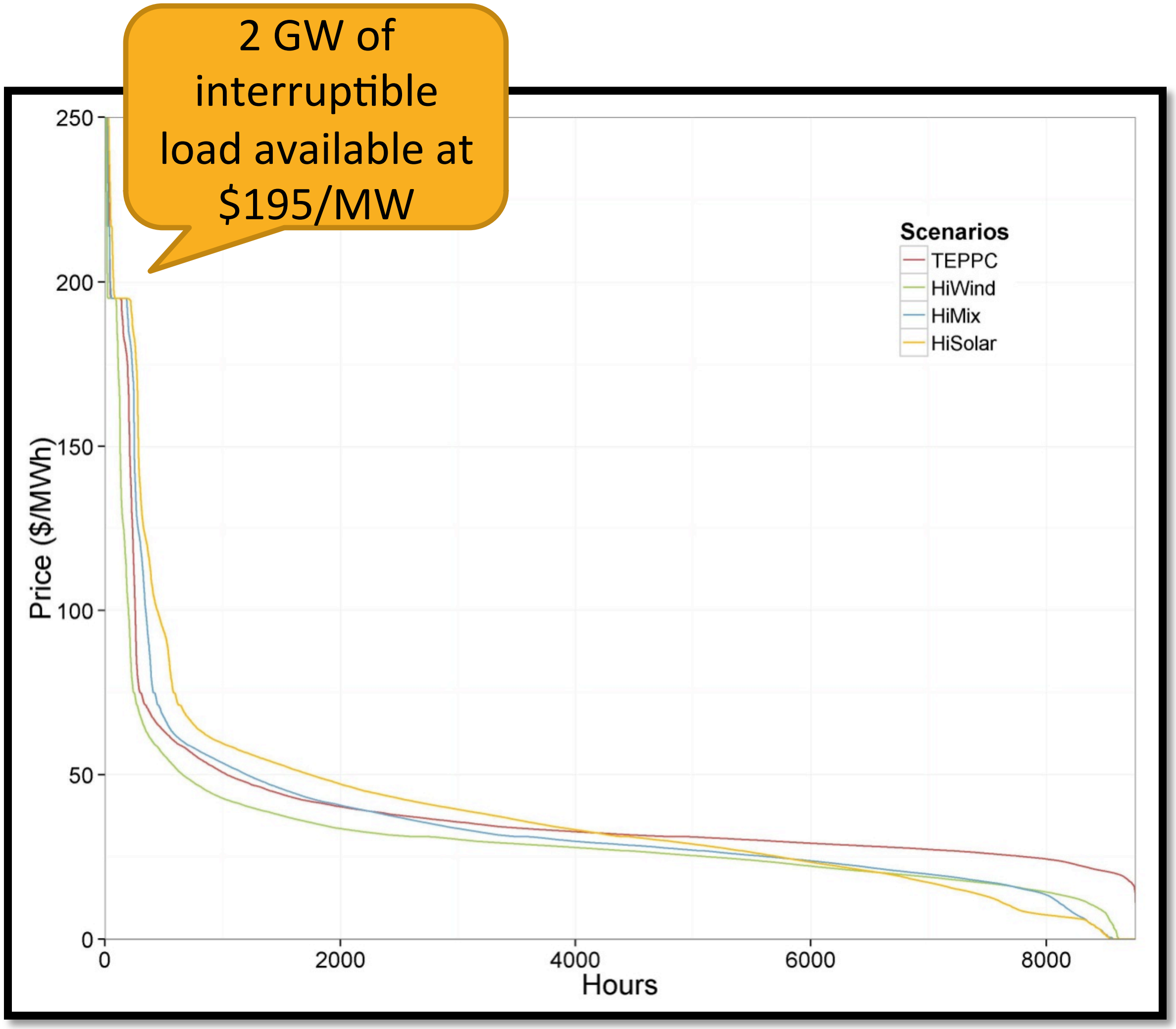


107-Curtailment-season



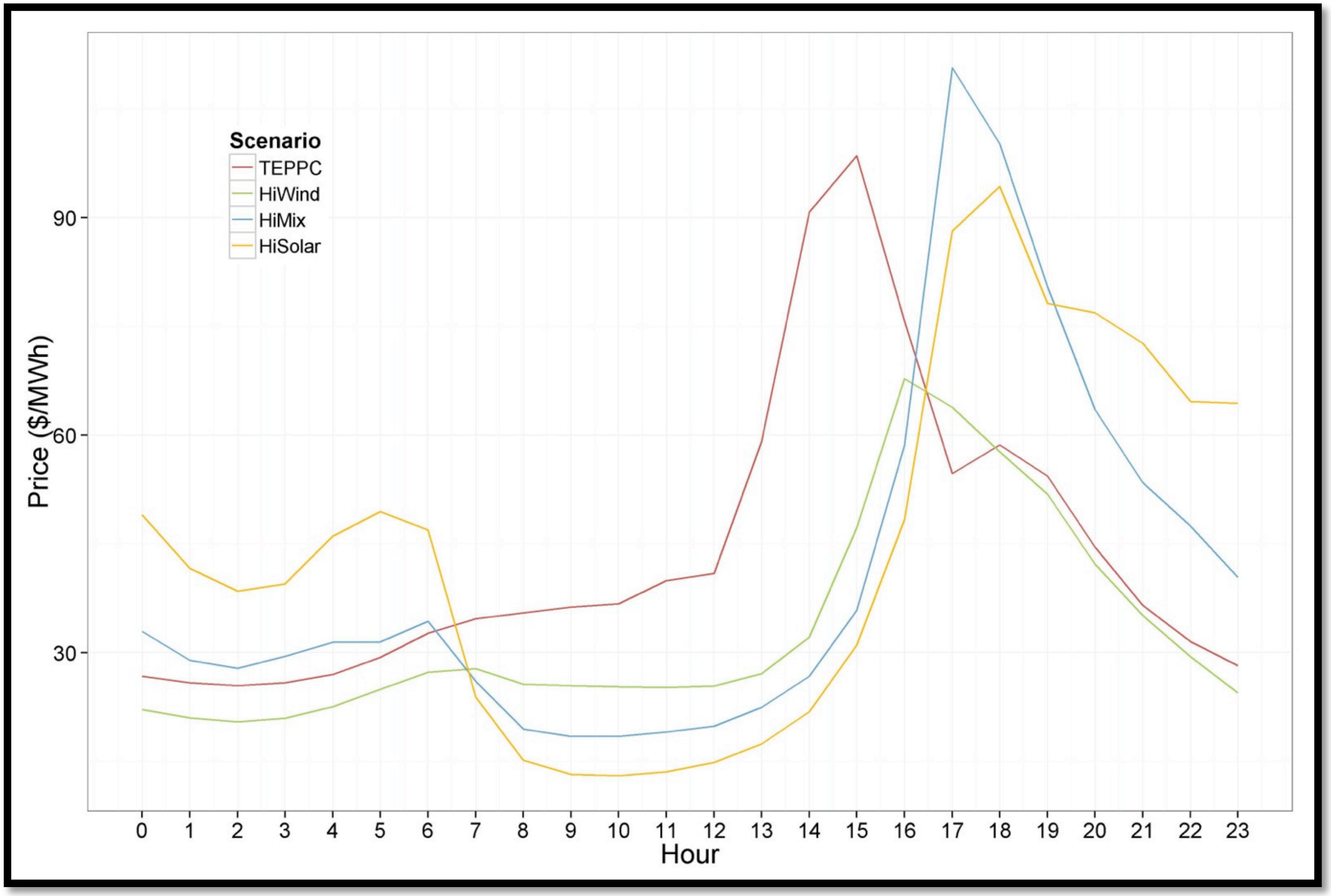
Results - prices

Price duration curve

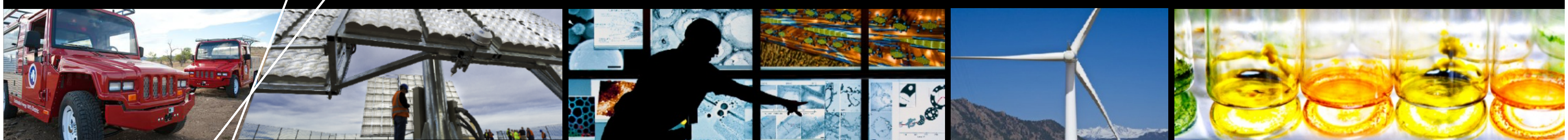


108-Price-duration

Hourly prices

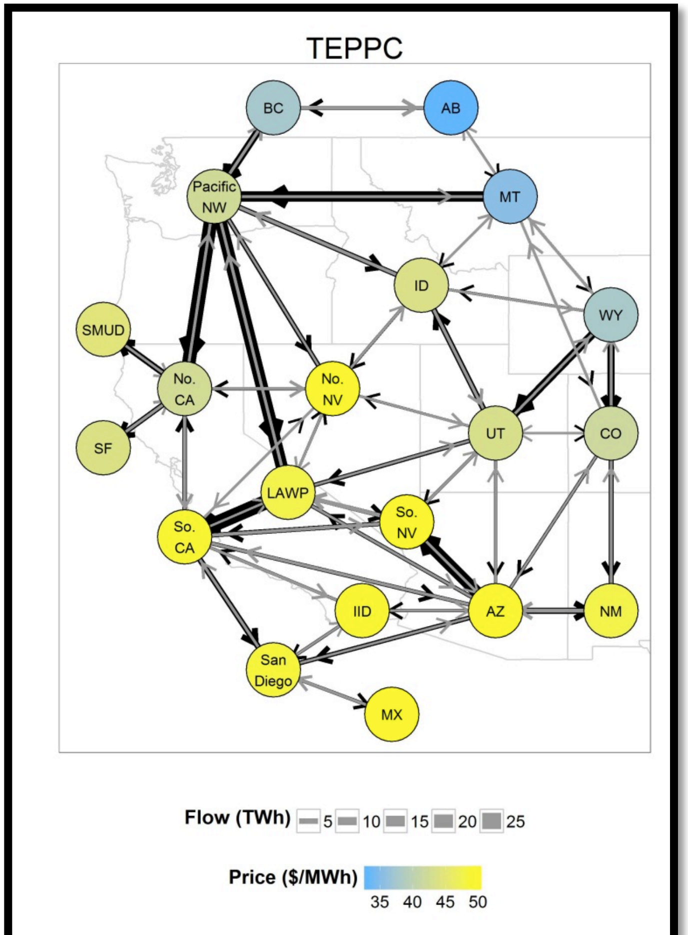


109-Price-hour



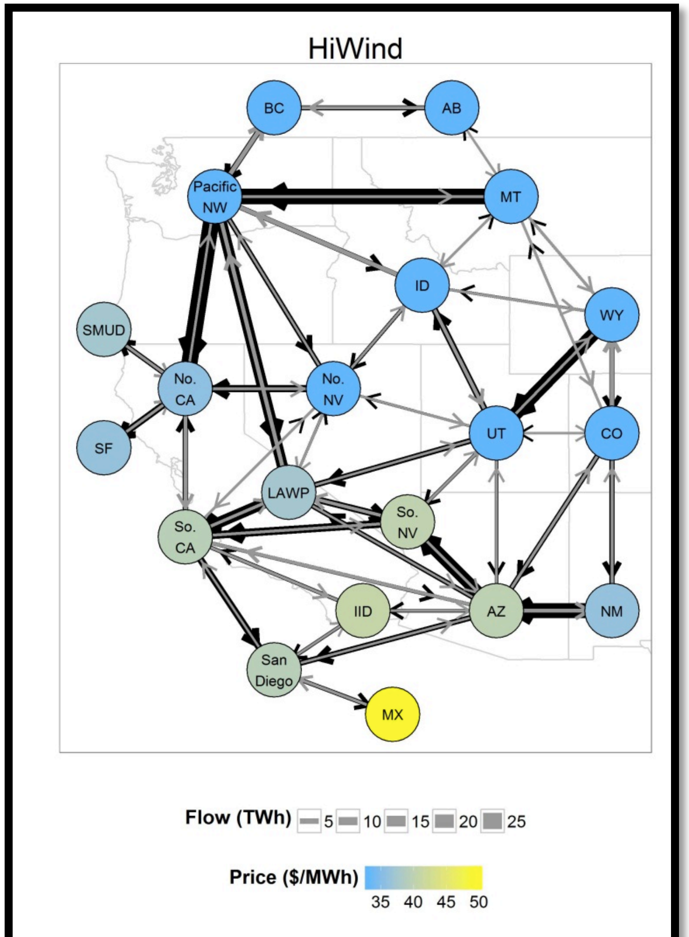
Results - transmission

TEPPC Flows/prices



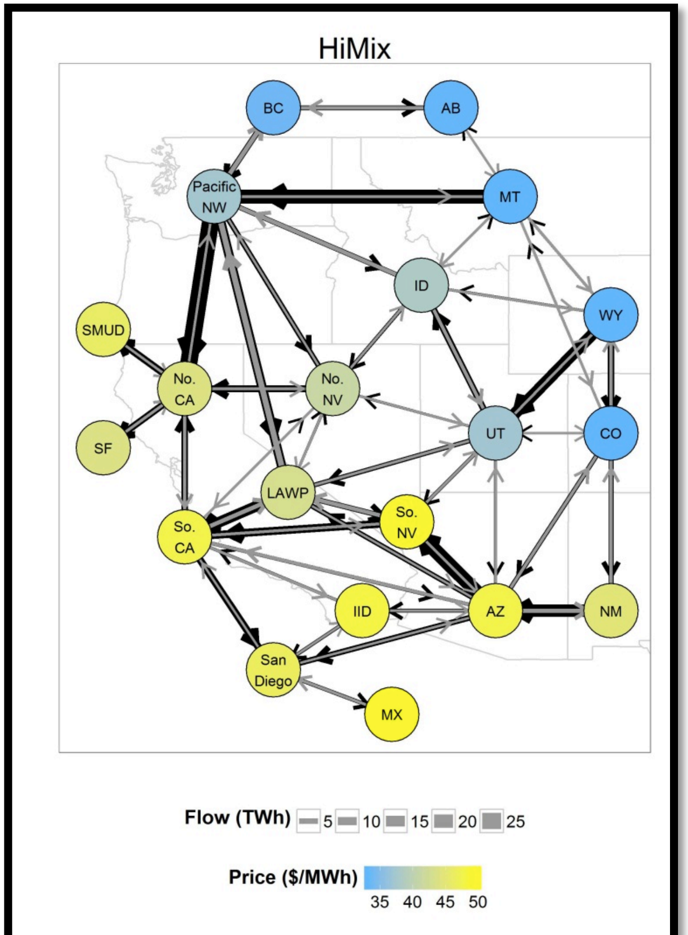
110a-MapFlowPrice_TEPPC

HiWind Flows/prices



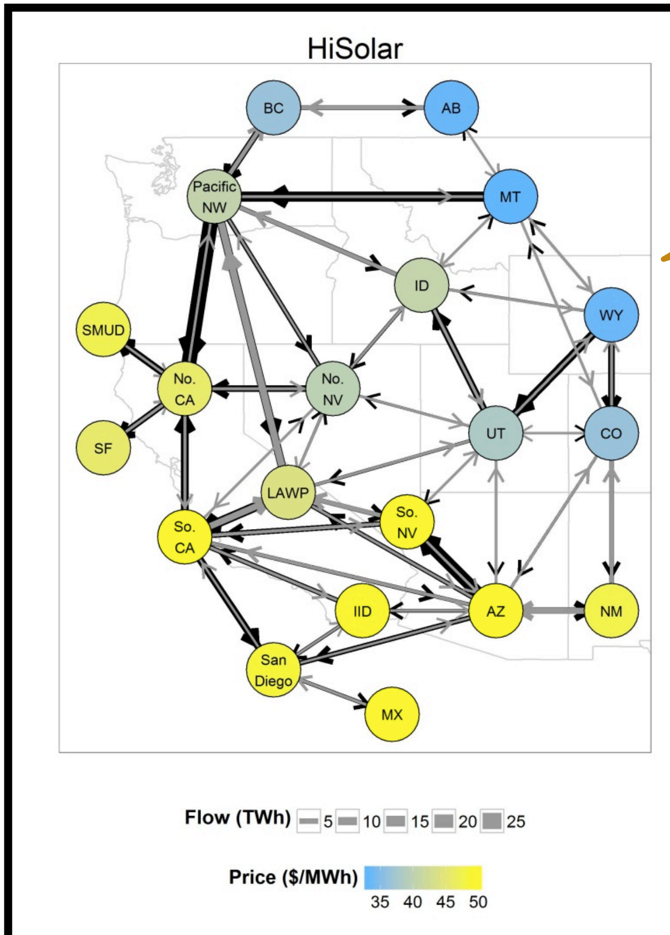
110b-MapFlowPrice_HiWind

HiMix Flows/prices



110c-MapFlowPrice_HiMix

HiSolar Flows/prices



110d-MapFlowPrice_HiSolar

HiSolar has lower flows than HiWind

For more details

- Results www.nrel.gov/docs/fy12osti/56171.pdf
  www.nrel.gov/docs/fy12osti/56217.pdf
- Emissions and wear and tear summary
  www.nrel.gov/docs/fy12osti/53504.pdf
- Wear and tear costs and impacts
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- Cycling Cost Analysis
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